# MISSOURI

# DROUGHT MITIGATION AND RESPONSE PLAN

## 2023

MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

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# List of Abbreviations

| | |
|---|---|
| AF | acre-feet |
| AMI | advanced metering infrastructure |
| ASR | aquifer storage and recovery |
| BRIC | Building Resilient Infrastructure and Communities |
| CAS | Crisis Action System |
| CDC | Centers for Disease Control and Prevention |
| CMI | Crop Moisture Index |
| CMOR | Condition Monitoring Observer Reports |
| CoCoRaHS | Community Collaborative Rain, Hail & Snow Network |
| CPC | Climate Prediction Center |
| CRP | Conservation Reserve Program |
| CWC | Climate and Weather Committee |
| CWT | hundredweight |
| DAC | Drought Assessment Committee |
| DEC | Drought Executive Committee |
| DEWS | Drought Early Warning System |
| DIR | Drought Impact Reporter |
| DRA | Delta Regional Authority |
| DSCI | Drought Severity and Coverage Index |
| DWSRF | Drinking Water State Revolving Fund |
| ECP | Emergency Conservation Program |
| EDA | Economic Development Administration |
| EDDI | Evaporative Drought Index |
| EIA | Energy Information Administration |
| ELAP | Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish Program |
| EO | executive order |
| EOC | Emergency Operations Center |
| EOP | emergency operations plan |
| EPA | U.S. Environmental Protection Agency |
| ET | evapotranspiration |
| FEMA | Federal Emergency Management Agency |
| FSA | Farm Service Agency |
| GAEPD | Georgia Environmental Protection Division |
| GCM | global climate model |
| GWh | gigawatt-hours |
| GWP | Global Water Partnership |
| HMA | Hazard Mitigation Assistance |
| HMGP | Hazard Mitigation Grant Program |
| HMP | hazard mitigation plan |
| IDMP | Integrated Drought Management Programme |
| IT | impacts team |
| LFP | Livestock Forage Program |
| M&I | municipal and industrial |
| MDA | Missouri Department of Agriculture |
| MDC | Missouri Department of Conservation |

| | |
|---|---|
| MG | millions of gallons |
| MGD | million gallons per day |
| MoDNR | Missouri Department of Natural Resources |
| MoDOT | Missouri Department of Transportation |
| MWh | megawatt-hours |
| NASS | National Agricultural Statistics Service |
| NCEI | National Centers for Environmental Information |
| NDI | NOAA Drought Index |
| NDMC | National Drought Mitigation Center |
| NIDIS | National Integrated Drought Information System |
| NOAA | National Oceanic and Atmospheric Administration |
| NRCS | Natural Resources Conservation Service |
| NRCS | National Resources Conservation Service |
| NREL | National Renewable Energy Laboratory |
| NRWA | National Rural Water Association |
| NWS | National Weather Service |
| PDSI | Palmer Drought Severity Index |
| PET | potential evapotranspiration |
| PHDI | Palmer Hydrological Drought Index |
| RMA | Risk Management Agency |
| SEMA | State Emergency Management Agency |
| SPEI | Standardized Precipitation Evapotranspiration Index |
| SPI | Standardized Precipitation Index |
| SVI | Social Vulnerability Index |
| SWSI | Surface Water Supply Index |
| USACE | U.S. Army Corps of Engineers |
| USDA | U.S. Department of Agriculture |
| USDM | U.S. Drought Monitor |
| USGS | U.S. Geological Survey |
| WIFIA | Water Infrastructure Finance and Information Act |
| WMO | World Meteorological Organization |

# Glossary

**Agricultural drought** – a type of drought determined by a combination of precipitation shortages; soil water deficits; reduced stream, lake, and groundwater levels; and other factors that impact crops and livestock.

**Climate division** – area of the state that has relatively uniform climate characteristics. These regions correspond to the crop reporting districts of the U.S. Department of Agriculture and have boundaries corresponding to county and state boundaries. There are six climate divisions in Missouri.

**Crop indemnity payments** – payments for crop damages from U.S. Department of Agriculture crop insurance policies.

**Crop reporting district** – area of the state that has relatively uniform climate characteristics. These regions were created by the U.S. Department of Agriculture National Agriculture Statistics Service and have boundaries corresponding to county and state boundaries. There are nine crop reporting districts in Missouri. Crop reporting districts are more representative of the spatial variability of precipitation in Missouri compared to climate divisions.

**Drought** – a period of abnormally low precipitation or excessive dryness that causes water supply shortages, impacts to agriculture and livestock, economic damages, and/or impacts on the environment.

**Drought categories** – five levels of drought used by the U.S. Drought Monitor (D0: abnormally dry, D1: moderate drought, D2: severe drought, D3: extreme drought, and D4: exceptional drought).

**Drought damages** – provides estimates of economic damages from drought to agriculture, municipal water supply, power production, and tourism and recreation.

**Drought indicators** – variables or parameters used to assess drought conditions. Examples include precipitation, temperature, streamflow, soil moisture, and reservoir levels.

**Drought indices** – computed representations of drought severity using drought indicators. Indices measure drought quantitatively and qualitatively on a given timescale and are used to assess the severity, location, timing, and duration of drought events.

**Drought management practices** – actions, restrictions, or policies implemented by individuals or entities in response to drought conditions.

**Drought response system** – a planning framework for determining the appropriate level of drought, the triggers that result in moving to the next phase of the drought response system, the mitigation and response actions to implement at each level of drought, and the individuals and agencies responsible for various actions during each phase.

**Ecological drought** – a type of drought characterized by a deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedback in natural and/or human systems. Ecological drought impacts may include reduced biodiversity, forest conversion, fish kills in streams, river degradation, and/or species migration.

**Essential water use** – water used for firefighting, health and medical purposes; maintaining minimum streamflow requirements; electric power generation; other essential facilities and infrastructure; reasonable amounts to sustain human life; and maintain reasonable standards of hygiene, cleanliness, and sanitation.

**Flash drought** – a type of drought that develops rapidly compared to conventional drought and is often driven by abnormally high temperatures, winds, and/or incoming solar radiation, which leads to high rates of evapotranspiration.

**Global climate model** – complex mathematical representation of the major climate system components (atmosphere, land surface, ocean, and sea ice) and their interactions. The earth's energy balance among the four components is the key to long-term climate prediction. Also known as general circulation models.

**Hydrological drought** – type of drought characterized by declines in streamflow, lake levels, or groundwater levels. Often measured on a watershed or river basin scale. While a hydrological drought originates with the meteorological deficit in precipitation, it is measured based on the impacts to the hydrologic system. Generally, hydrologic impacts and deficiencies lag meteorological and agricultural indicators.

**Impact** – measured mainly by the economic value of drought impacts. Impacts are determined by a mostly quantitative assessment that considers the direct economic impacts to agriculture, municipal water supplies, power production, and tourism/recreation. Indirect, secondary, and hard-to-quantify impacts may be qualitatively determined.

**Likelihood** – probability of a drought of a certain intensity and severity occurring in a given location or region. Likelihood is determined with a quantitative assessment based on a combination of historical drought probability and future climate conditions.

**Meteorological drought** – type of drought characterized by deficiencies in monthly or seasonal precipitation. May also be characterized by higher-than-average temperatures, high winds, low relative humidity, and less cloud cover.

**Municipal water use** – public water supply systems, self-supplied residences, and self-supplied businesses. (This broad definition is unique to this plan, and is not a legal definition)

**Nonessential water use** – categories of water use other than essential water use, which may be restricted or prohibited during severe or extreme drought.

**Once-through cooling** – using large volumes of water for cooling purposes and immediately returning the water to a body of water as opposed to using cooling towers to recirculate cooling water.

**Resilience** – a measure of the speed and effectiveness in responding to drought for a given location or region. In the context of this plan, resilience is measured mostly by a qualitative assessment that considers ease and ability to access alternative sources of water, interconnectedness of water systems, and the Social Vulnerability Index.

**Snow drought** – type of meteorological drought specific to snowfall. A dry snow drought is a result of low winter precipitation, and a warm snow drought occurs when warm conditions reduce the ability of winter precipitation to accumulate as snowpack.

**Socioeconomic drought** – considers the impacts of meteorological, agricultural, or hydrologic droughts on supply and demand of economic goods. Socioeconomic drought occurs when there is a weather-related shortfall in water supply that is exceeded by the demand for water to meet an economic need.

**Susceptibility** – a measure of the available water supplies and the demands for a given location or region. Determined by a mostly quantitative assessment that considers the sources of water available for use, the quantity of water available for use, current and future water demands based on population, and other factors that influence demand such as conservation and climate change.

**U.S. Drought Monitor (USDM)** – an organization that monitors drought and releases weekly publications on drought across the United States. The USDM has developed standardized drought levels, which are commonly used in drought planning, forecasting, and response across the country.

**Willingness to pay** – an economic estimate of what customers would be willing to pay for a given service or to avoid a loss of service, often a higher dollar value than the actual cost of service, thus indicating the importance of the service to the customer's lifestyle.

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# Section 1 Introduction

## 1.1 Background

Missouri's climate is characterized by hot, humid summers, cold winters, and variable seasonal precipitation. Historically, mean annual precipitation for Missouri is approximately 43 inches; however, precipitation varies throughout the state from an annual low of 34 inches in the northwest to a high of 50 inches in the southeast. Particularly during summer months, when loss of water by evaporation and transpiration is high, infrequent rainfall can lead to drought conditions. Nearly every year, portions of the state have short periods of drought, and severe droughts have been experienced multiple times in the history of Missouri, most recently in 2012 and 2018. While droughts are often short term, lasting from weeks to a few months, drought can persist into multiyear events, intensifying impacts and escalating the need for adequate and efficient drought mitigation and response. Drought planning or preparation includes proactive actions taken by individuals, industries, government, and others in advance of water shortages to mitigate some of the impacts and conflicts associated with drought. Drought response is reactive mitigation action taken during a drought to reduce its impacts on people, the environment, and the economy.

This Missouri Drought Mitigation and Response Plan is intended to aid state, federal, and local government officials; commercial, industrial, and private water users; and public and private water suppliers in planning and responding to drought events in Missouri. The primary goals of the plan are to serve as an information source for reducing drought impacts, increasing public awareness, enhancing resiliency, promoting water conservation, adapting to climate change, improving monitoring, facilitating response planning, and clarifying roles and responsibilities. This plan is an update to the 2002 Missouri Drought Plan published by the Missouri Department of Natural Resources Water Resources Program. It builds and expands upon data and information in the Missouri Water Resources Plan 2020 Update and the 2018 Missouri State Hazard Mitigation Plan (HMP).

A key component of this plan is the assessment of Missouri's drought history and an examination of past direct and indirect drought impacts. Potential future impacts are estimated by region for each major water use sector. Another key component is the assessment of regional vulnerability using a combination of the elements of likelihood, susceptibility, impact, and resilience. **Figure 1-1** defines each of these elements and summarizes how they are quantitatively or qualitatively evaluated in this plan. These four elements expand on the regional assessment of drought susceptibility presented in the 2002 Missouri Drought Plan and the county-level assessment of drought vulnerability presented in the 2018 Missouri State HMP. Within this plan, each element is assessed regionally to aid in identifying and selecting drought mitigation options and strategies that best address the elements that most contribute to drought vulnerability for a particular region and water use sector.

Drought **vulnerability** is the combination of:

### Likelihood

*What is the probability of a drought of a certain intensity and severity occurring in a region?*

A quantitative assessment based on a combination of historical drought probability and potential future conditions.

- Historical drought probability will be determined from 1895-2016 PDSIs by county (as calculated in the 2018 Missouri State Hazard Mitigation Plan).
- Potential future conditions will be estimated based on changes to the PDSI, as calculated from climate model predicted temperature and precipitation.

### Impact

*What are the potential impacts to a region if a drought were to occur? What is the economic cost of those impacts?*

A mostly quantitative assessment that considers the direct, economic impacts to:

- Agriculture
- Municipal water supplies
- Power production
- Tourism/recreation

Indirect, secondary, and hard-to-quantify impacts are qualitatively considered.

### Susceptibility

*What are the primary sources of water, how much water is available, and what are the current and projected water demands in a region?*

A mostly quantitative assessment that considers the:

- Sources of water available for use and the amount available
- Current and future demands, by sector, based on current population and future projections, and considering other factors that influence demand, such as the level of conservation and climate change.

### Resilience

*What technical and financial resources are available and how quickly and effectively can each region respond to drought?*

A mostly qualitative assessment that considers the:

- Ease and ability to access alternative sources of water
- Interconnectedness of water systems
- Amount of storage in reservoirs, livestock ponds, etc.
- Social Vulnerability Index (SoVI) and other assessments of technical and financial resources, in areas deemed especially susceptible to drought.

**Figure 1-1. Elements Used to Characterize Drought Vulnerability**

## 1.2 Report Organization

**Section 2** defines the types of drought that may impact the state and provides an overview of potential impacts from each drought type. It discusses drought history in Missouri by type, regions affected, impacts, severity, and length followed by a discussion of drought management strategies and examples at the state level. **Section 3** includes a quantification of current water use, building on the data analysis completed as part of the Missouri Water Resources Plan 2020 Update. Regional differences in water sources and source constraints are discussed and used to assess regional resiliency to drought. **Section 4** identifies damages from drought and provides estimates of economic drought damages to agriculture, municipal water supply, power production, and tourism and recreation. **Section 5** discusses regional likelihood and susceptibility to drought, and along with the evaluations of resilience and damages, identifies the regions most vulnerable to drought. **Section 6** presents the state drought mitigation goals and summarizes state, federal, and local capabilities, roles, and responsibilities, including those of the state Drought Advisory Committee. It also provides an overview of drought mitigation funding opportunities for drought mitigation and response. **Section 7** presents the most important actions and strategies for preparing and responding to drought. Finally, **Section 8** presents a comprehensive matrix of drought actions and strategies. These actions are intended to assist federal, state, and local entities to prioritize and develop preparedness and mitigative drought actions.

### Overview of Missouri Drought Mitigation and Response Plan Sections

Plan sections are organized as follows:

- Section 2 Assessment of Drought Types and Impacts – discusses the different types of drought, highlights potential impacts from drought, summarizes the history of drought in Missouri, and provides an overview of strategies to prepare for and respond to drought.
- Section 3 Current Use and Resiliency Assessment – discusses current water use, including sources of supply and regional source constraints. It also identifies factors that improve drought resilience and assesses the use of these factors on the regional scale.
- Section 4 Assessment of Drought Related Damages – identifies damages from drought events and provides estimates of economic damages from drought water use sectors. Secondary, indirect effects are also identified.
- Section 5 Assessment of Drought Vulnerability – discusses the likelihood, susceptibility, and overall vulnerability to drought by region within Missouri.
- Section 6 Drought Mitigation Capabilities – introduces Missouri's drought mitigation goals and summarizes federal, state, and local capabilities, roles, and responsibilities.
- Section 7 Drought Response System and Recommendations – provides major recommendations for drought planning and response.
- Section 8 Matrix of Drought Actions – provides federal, state, and local preparedness and drought response actions organized by water use category and applicable drought response phase.

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# Section 2 Assessment of Drought Types and Impacts

## 2.1 Introduction

This section identifies and defines the types of drought that may impact Missouri, summarizes the history of drought and its impact to the state, and provides an initial identification of general drought mitigation and response options. The strategies to prepare for and respond to drought are further developed in Section 7, Drought Mitigation and Response.

> **Overview of Section 2 Assessment of Drought Types and Impacts**
>
> This section discusses the different types of drought, highlights potential impacts from drought, summarizes the history of drought in Missouri, and provides an overview of strategies to prepare for and respond to drought. Subsections are organized as follows:
>
> - Section 2.2 Defining Drought – presents the conceptual and operational definitions of drought and introduces indicators and indices used to monitor drought.
> - Section 2.3 Drought Impacts – identifies potential impacts from drought in Missouri.
> - Section 2.4 History of Drought, Drought Monitoring, and Drought Response in Missouri – summarizes the history of drought in Missouri, focusing primarily on recent droughts.
> - Section 2.5 General Mitigation, Assessment, and Response Options – provides an overview of drought mitigation, assessment, and response options and strategies.

## 2.2 Defining Drought

Drought is generally defined as a lack of precipitation over an extended period that results in a water shortage. However, given the many different types of drought and the multitude of environmental, social, and economic impacts, numerous definitions of drought have been developed. These definitions can be categorized as *conceptual*, which focuses on the idea or concept of drought, or *operational*, which relates to how a drought functions or how it can be measured. Conceptually defining drought is useful when establishing drought policy. Conceptual definitions are specific to the type of drought or water use sector most impacted. For example, a hydrologic drought could be defined as a reduction in streamflow, reservoir levels, and aquifer levels, resulting in reduced water supply availability. The operational definitions of drought typically describe the degrees of departure from climatic variables to analyze drought frequency, severity, and duration. Operationally defining drought helps water users, policy makers, and resource planners in recognizing and planning for drought (National Drought Mitigation Center [NDMC] 2021a).

### 2.2.1 Drought Types and Timescales

Drought types have traditionally been defined by how they develop and their impacts. It is also important to recognize and record droughts based on timescales. Droughts are typically defined as meteorological, hydrological, agricultural, socioeconomic, or ecological. Meteorological and hydrological droughts are defined by how they develop, and can be linked with agricultural, socioeconomic, and/or ecological droughts based on their primary impacts. Within each of these drought types, droughts can also be classified as short-term or long-term. Periods of precipitation deficit that last for a few weeks or months are considered short-term droughts. Indicators used to monitor short-term drought include topsoil moisture and streamflow, and indices used to monitor for short-term drought impacts include the Standardized Precipitation Index (SPI), Palmer Z Index, and Crop Moisture Index (CMI). Periods of precipitation deficit and drought patterns that last more than 6 months are typically considered long-term droughts (NDMC

2021a). Indicators used to monitor long-term drought impacts include reservoir storage and groundwater levels. **Figure 2-1** depicts the general sequence of drought types and common drivers.

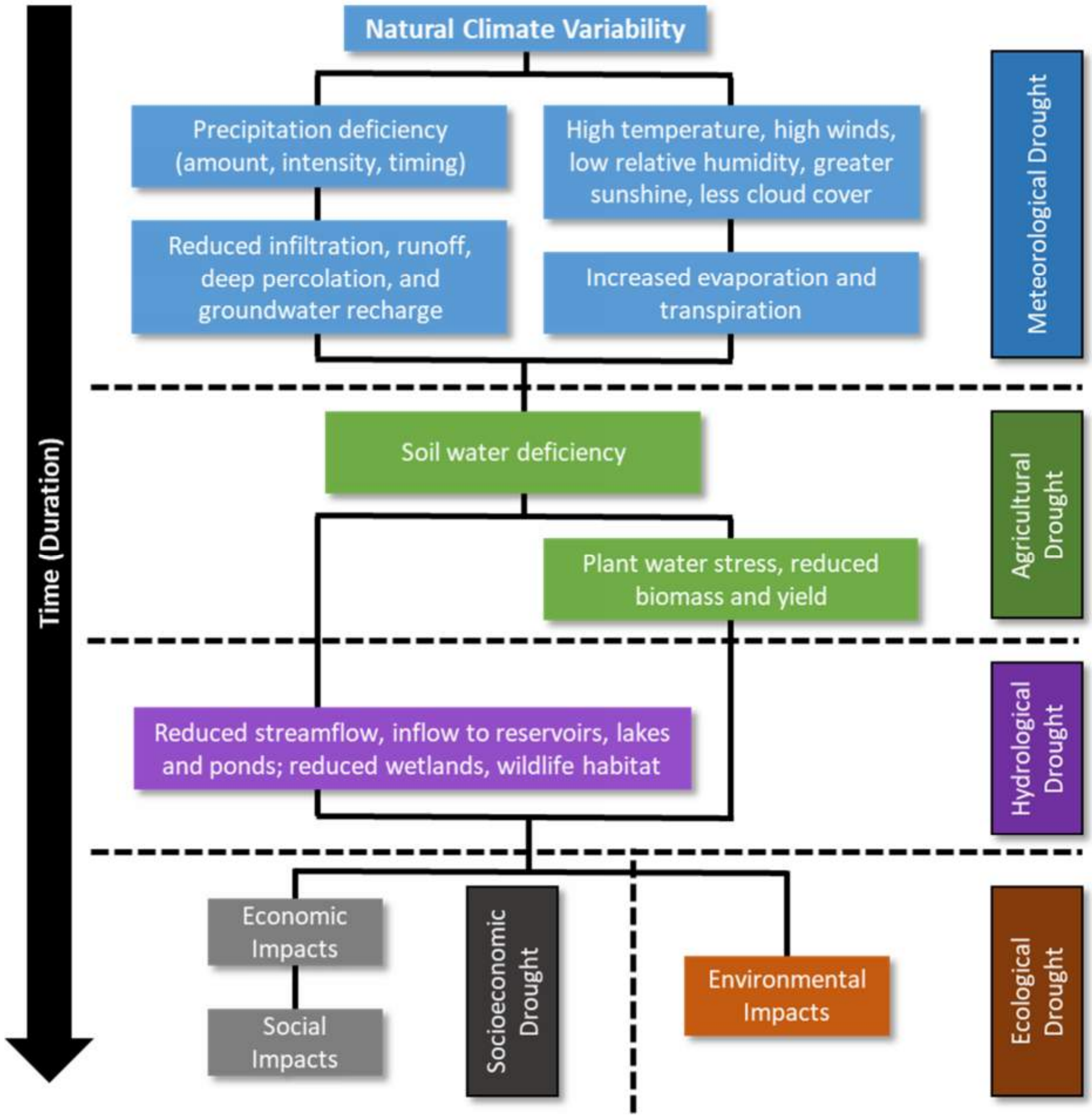


**Figure 2-1. Sequence of Drought Types and Common Drivers**
*Adapted from NDMC*

Drought can also develop rapidly, in what is referred to as flash drought. In addition to the lack of precipitation associated with conventional drought, flash droughts are often driven by abnormally high temperatures, winds, and/or incoming solar radiation, which leads to high evapotranspiration (ET) rates.

In most of the central United States, a meteorological drought may be defined by deficiencies in monthly or seasonal precipitation. Additionally, a meteorological drought may also be characterized by higher-than-average temperatures, high winds, low relative humidity, and less cloud cover. All regions of Missouri may experience meteorological drought; however, a review of historical Palmer Drought Severity Indices (PDSIs) indicates precipitation deficiencies are more common in the Northwest Prairie and Northeast Prairie

climate divisions (Missouri Department of Public Safety 2018). A snow drought is a type of meteorological drought that may have indirect impacts on water supply in Missouri. When snow drought occurs northwest of Missouri, it could impact Missouri River Basin inflows and reduce flows in the Missouri River. There are two types of snow drought: dry snow drought, which results from low winter precipitation, and warm snow drought, which occurs when warm conditions reduce the ability of winter precipitation to accumulate as snowpack. A dry or warm snow drought in areas northwest of Missouri that provide runoff to the Upper Missouri River Basin may result in reduced snowmelt-derived flows between March and August as the Missouri River enters the state.

A hydrological drought is measured by declines in streamflow, lake levels, or groundwater levels. Hydrological drought is often measured on a watershed or river basin scale. While a hydrological drought originates with a meteorological deficit in precipitation, it is measured based on the impacts to the hydrologic system. Generally, hydrologic impacts and deficiencies lag meteorological and agricultural indicators. For example, it may take several months for precipitation deficiencies to cause declines in reservoir levels. During a short-term drought, declines in surface water flows may impact water supplies for agriculture, municipal and industrial water supply, hydropower production, recreation, and ecosystem habitat. In long-term drought conditions, hydrological impacts may include aquifer depletion, subsidence, permanent loss of storage for groundwater, and infrastructure damage. Hydrologic droughts may occur in every region of the state. Drought occurring outside of Missouri can also result in hydrological impacts within the state, specifically where rivers and streams flow into the state and help maintain reservoir levels, such as in the Northwest, North Central, Northeast, and Southwest regions.

An agricultural drought may be determined by a combination of precipitation shortages; soil water deficits; reduced stream, lake, and groundwater levels; and other factors that impact crops and livestock. Soil water deficiencies in an agricultural drought may lead to plant water stress and reduced biomass and yield. Impacts during a short-term drought may include damage to crops from depletion of topsoil moisture. Shallow-rooted plants, such as corn and wheat crops, are often the first impacted. Long-term and short-term droughts can result in complete crop and forage failure and livestock sell-offs. Impacts from agricultural drought have occurred historically throughout Missouri; however, the Northeast, North Central, and Northwest regions are the most vulnerable to extensive impacts associated with agricultural drought based on water availability and crop acreage.

A socioeconomic drought considers the impacts of meteorological, agricultural, or hydrologic droughts on supply and demand of economic goods. Socioeconomic drought occurs when there is a weather-related shortfall in water supply that is exceeded by the demand for water to meet an economic need. All regions of the state may experience a socioeconomic drought, although the economic drivers and impacts in each region are likely to differ.

An ecological drought is a deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedback in natural and/or human systems. Ecological drought impacts may include reduced biodiversity, forest conversion, fish kills in streams, river degradation, and/or species migration. Short-term droughts may cause woody plants such as trees and shrubs to wilt, while long-term drought may cause native plants to die back and allow invasive plant species to intrude. Changes in plant cover during long-term drought reduce habitat for wildlife and affect water resources. Dry vegetation and higher-than-average temperatures can also leave regions more susceptible to wildfire. All regions of the state may experience ecological drought, although the impacts may differ substantially based on the type of ecosystems present. The temperate forest of the Missouri Ozarks in southern Missouri are vulnerable to ecological drought based on the ecological diversity and importance of this region.

### 2.2.2 Missouri's Climate

Understanding climate records and trends in Missouri is important to understanding drought. Missouri's climate is driven by its inland location and lack of mountain barriers to airflow from the north and south, resulting in a climate characterized with hot, humid summers and cold winters. Long-term average annual precipitation throughout Missouri over the past 125 years is 41.1 inches annually, ranking it 24th nationwide for precipitation (Missouri Climate Center 2021a). The National Oceanic and Atmospheric Administration (NOAA) calculates climate normals using a 30-year period from 1991 to 2020, which results in a mean annual precipitation of 43.5 inches for Missouri. As shown in **Figure 2-2**, the 30-year mean annual precipitation varies across the state, from a low of 34 inches in the northwest to a high over 50 inches in the southeast. Seasonal precipitation varies widely. In northwestern Missouri, June precipitation averages five times greater than January precipitation, while in southeastern Missouri, precipitation has minimal seasonality because of the greater influences of subtropical air throughout the year (Decker 2018).

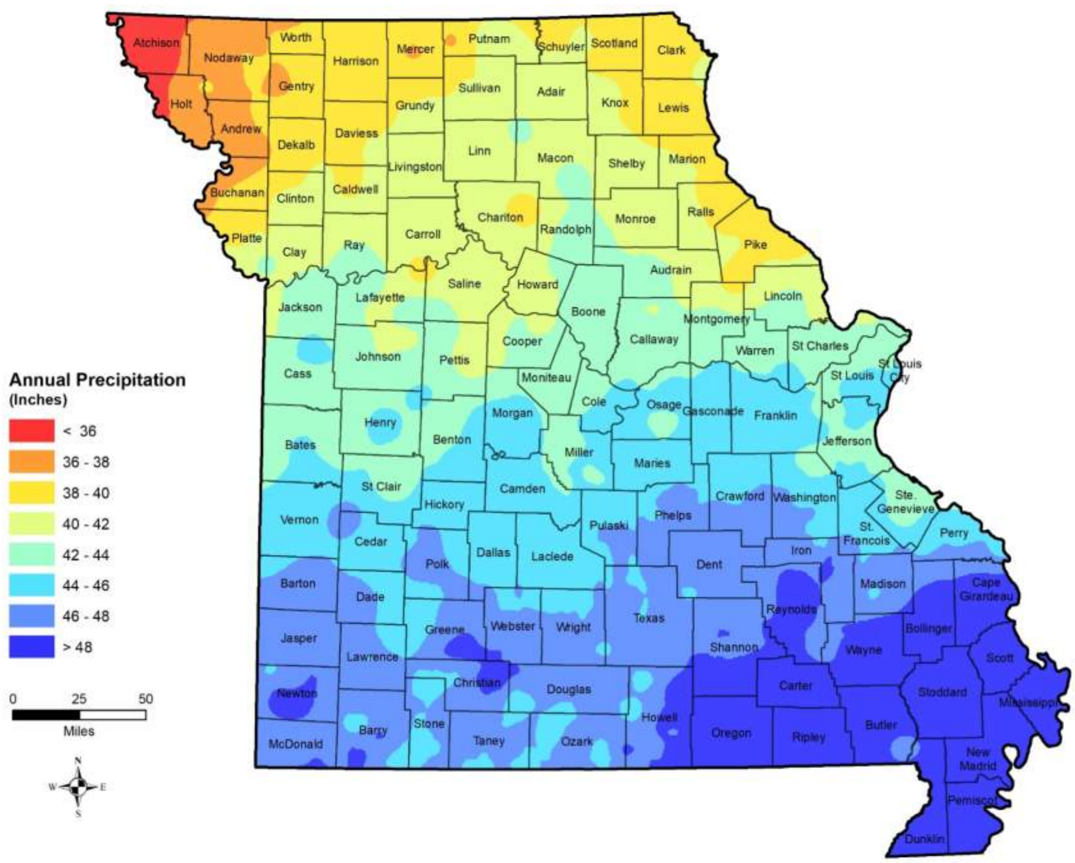


**Figure 2-2. Missouri Mean Annual Precipitation, 1991–2020**
*Source: PRISM Climate Group, Oregon State University*

The U.S. Department of Agriculture (USDA) National Agriculture Statistics Service designates nine crop reporting districts for Missouri, as shown in **Figure 2-3**, which is the spatial resolution typically used in this drought mitigation and response plan.

Crop reporting districts were selected because they are more representative of the spatial variability of precipitation than other geographic types that cover larger areas (Guinan 2004). Spatial variability of precipitation is the most relevant climate variable in regard to drought. Therefore, this plan will summarize information by crop reporting districts, also referred to as *regions*, unless explicitly stated otherwise.

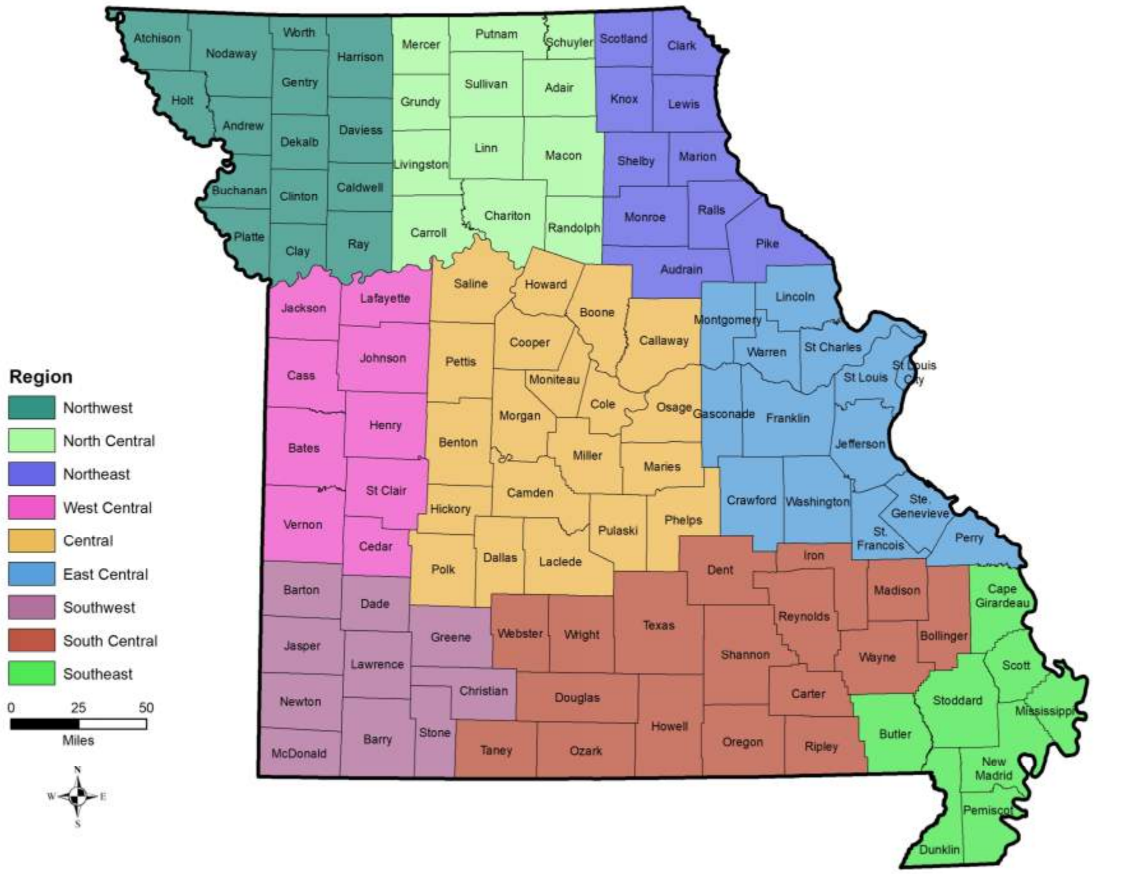


**Figure 2-3. Missouri Crop Reporting Districts**

All of Missouri is vulnerable to extreme precipitation conditions, in the form of both floods and droughts. High temperatures during summer months lead to greater water loss from the top layers of soil resulting from high evaporation and transpiration. If precipitation does not occur at frequent intervals, or with enough intensity to replenish water loss, a drought will occur. Short periods of drought occur nearly every year in portions of Missouri, while longer, prolonged droughts occur more infrequently but can cause widespread distress.

Droughts in Missouri can be a statewide, regional, or localized problem. They also can occur at various timescales. Portions of the state have experienced long-term droughts lasting several years, and short-term droughts lasting several weeks to months. Drought conditions can evolve slowly or can occur with rapid onset. Regardless of the geographic location and timescale of the drought, it can lead to devastating impacts statewide. Monitoring and proactive planning for drought conditions is extremely important in mitigating these impacts.

### 2.2.3 Drought Indicators, Indices, and Monitoring Tools

Drought indicators are variables or parameters used to assess drought conditions. Examples include precipitation, temperature, streamflow, soil moisture, and reservoir levels. Drought indices are computed representations of drought severity using drought indicators. Indices measure drought quantitatively and qualitatively on a given timescale and are used to assess the severity, location, timing, and duration of drought events. Indicators and indices are especially helpful to agencies that monitor drought and guide early warning and response.

Several agencies in Missouri, regionally, and nationally monitor potential drought indicators and indices on a weekly basis. Nationally, NDMC, USDA, and NOAA collaborate on drought monitoring to produce the U.S. Drought Monitor (USDM). Regionally, the Midwestern Regional Climate Center tracks climate conditions in nine midwestern states. Locally, the Missouri Climate Center at the University of Missouri monitors temperature, precipitation, and drought indices within Missouri.

Development of new indices and tools over the past 20 years has allowed many agencies to shift from using a single index or indicator to monitor drought and guide the early warning process, to using multiple indices and monitoring tools based on a variety of indicators. Over the past decade, composite or hybrid indicators have been developed to merge different indicators or indices into a single, manageable tool for decision-makers, referred to as a monitoring tool.

Indicators and indices are selected for drought planning purposes based on several factors. In some cases, monitoring tools are selected based on their use of multiple drought indices, ground truthing, and expert input. Some of the more commonly used drought indices and monitoring tools and their relationship to drought planning are summarized in the following paragraphs.

> Drought indicators and indices provide useful triggers to help agencies monitor, prepare for, and respond to drought conditions.

### *Drought Indices*

- **Standardized Precipitation Index (SPI):** The SPI is a drought index developed in 1993 that shows historical precipitation data compared to a specific time period of precipitation for various timeframes. For example, a 3-month SPI compares precipitation over a specific 3-month period with precipitation totals for the same three-month period for all years included in the historical record. The resulting SPI value is interpreted as the number of standard deviations by which the observed or recent time period deviates from the long-term historical mean precipitation. An index of zero indicates the historical median precipitation amount. A negative index represents dry conditions (and may represent a drought) and a positive index indicates wet conditions. The SPI is calculated on several timescales ranging from 1 to 48 months to capture short- and long-term drought. The SPI uses only precipitation data, which makes it easy to use and calculate (World Meteorological Organization [WMO] and Global Water Partnership [GWP] 2016). While the stand-alone use of precipitation data is considered a key strength because it is easy to use and comparable across regions, it is also considered a limitation, as the index does not account for temperature and ET, nor does it consider the intensity of precipitation (Keyantash et al. 2018).

  SPI can be used to view both short- and long-term conditions based on the chosen timescale. **Figure 2-4** illustrates national SPI maps at 1-, 6-, and 12-month intervals. Monitoring of short-term conditions can help identify short-term soil moisture deficits and crop stress, while a 3- or 6-month SPI provides a seasonal estimate of precipitation. The longer SPI intervals characterize precipitation patterns that are likely to have more influence on streamflow, reservoir levels, and groundwater levels than shorter intervals.

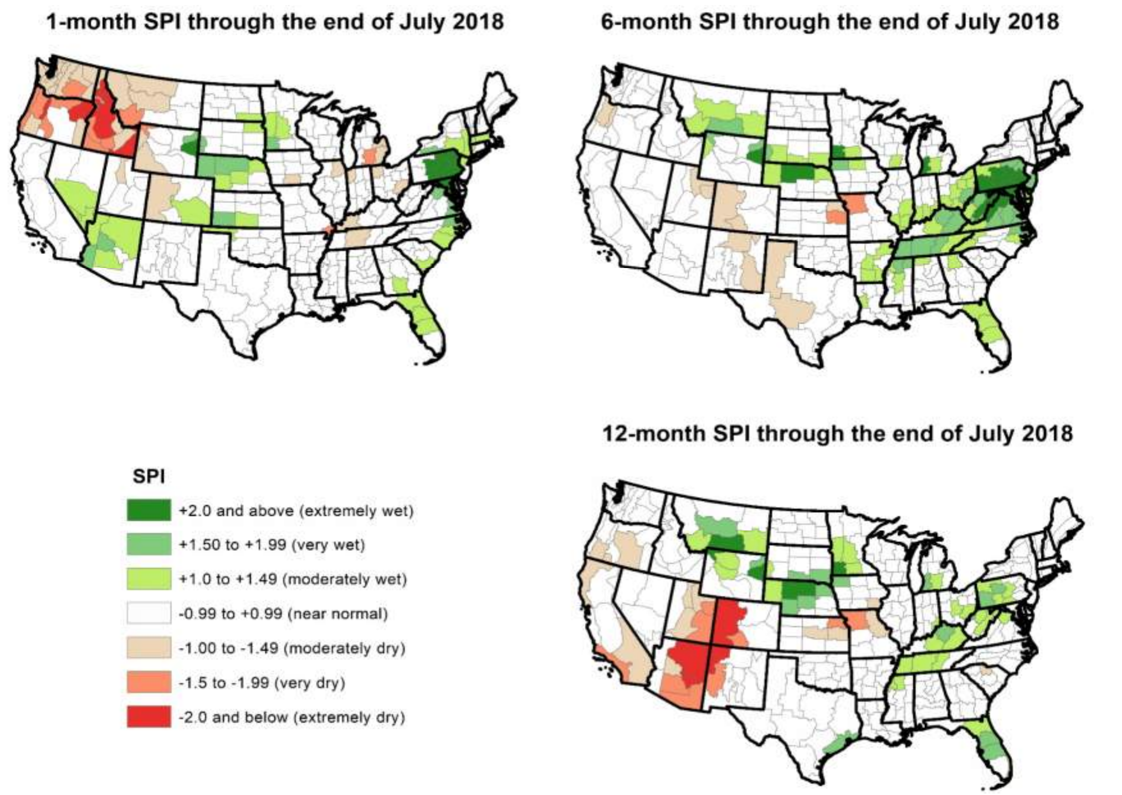


**Figure 2-4. United States Standardized Precipitation Index Maps by Climate Division**
*Source: NDMC*

- **Standard Precipitation Evapotranspiration Index (SPEI):** The SPEI is an extension of the SPI and uses precipitation with a temperature component that is used to determine potential evapotranspiration (PET). The SPEI can be calculated on a timescale of 1 to 48 months and has an intensity scale similar to the SPI, with positive and negative values that identify wet and dry events. A key strength of the SPEI over the SPI is that it captures the impact of increased temperature in addition to precipitation (Vicente-Serrano et al. 2015). However, it is not ideal for identifying rapidly developing drought situations since it is a monthly index.

- **Palmer Drought Severity Index (PDSI):** The PDSI was originally developed in 1965 and is the first index that was developed for measuring drought. The PDSI categorizes levels of wetness and dryness using monthly temperature and precipitation data along with information on the water-holding capacity of soils. PDSI values range from -10 (very dry) to +10 (very wet), with zero being normal, but it is typically shown on a national level at a scale of -4 to +4. A moderate drought value is -2, and conditions of extreme drought start at -4. The PDSI is most useful for measuring long-term drought and abnormal dryness or wetness. It has been used to designate disaster areas and reflect long-term status of water supply; however, the values have been shown to lag or respond slowly, making it less useful in detecting emerging and short-term drought situations (Dai et al. 2019). **Figure 2-5** illustrates the PDSI for each Missouri climate division in July of 2018. The Northwest Prairie was experiencing severe drought according to the PDSI categorization.

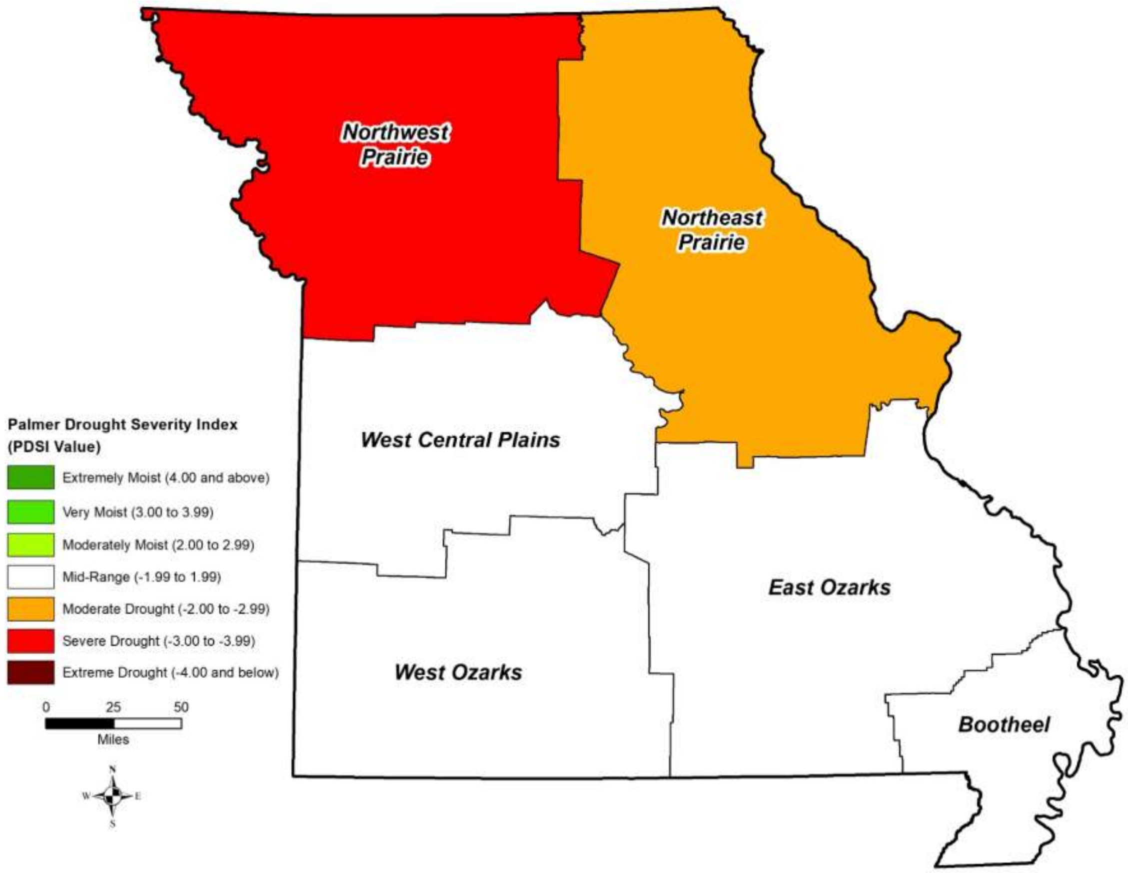


**Figure 2-5. Palmer Drought Severity Index Map by Climate Division, July 2018**
*Source: NOAA*

- **Palmer Z Index:** The Palmer Z Index is a derivative of the PDSI and is typically calculated for shorter timescales, allowing it to better represent short-term conditions and identify rapidly developing drought better than the PDSI. It is useful for comparing current periods to other known drought periods (WMO and GWP 2016).

- **Palmer Hydrological Drought Index (PHDI):** The PHDI is another derivative of the PDSI and measures long-term hydrological impacts of drought such as water storage, streamflow, and groundwater. This long-term index responds more slowly to changing conditions than the PDSI (WMO and GWP 2016).

- **Crop Moisture Index (CMI):** The CMI is an extension of the PDSI that considers agricultural drought impacts. The CMI is calculated by subtracting the difference between PET and moisture to indicate short-term moisture supply for crop-producing regions. PET is the amount of evaporation from soils and transpiration from plants that would occur if a sufficient water source were available. The CMI is calculated on a week-to-week timescale and is not a long-term drought monitoring tool (NDMC 2021b).

- **Surface Water Supply Index (SWSI):** The SWSI was developed in 1982 and incorporated water supply data into the PDSI. This index is calculated at the basin level and identifies the approximate frequency of mild drought occurrence to identify drought conditions associated with hydrological fluctuations (WMO and GWP 2016).

- **NOAA Drought Index (NDI):** The NDI was developed in the early 1980s as an indicator of how drought conditions affect agriculture. The index is precipitation-based, comparing weekly actual precipitation with normal 8-week average precipitation values during the growing season. If the actual precipitation is at 60 percent or less of the normal precipitation, the current week is considered to have water stress (WMO and GWP 2016).

### *Drought Monitoring Tools*

- **U.S. Drought Monitor (USDM):** The USDM was developed in 1999 by NDMC at the University of Nebraska-Lincoln, NOAA, and USDA. The USDM map is released weekly and provides a regional depiction of areas and intensity of drought using five classifications on a scale of D0 (abnormally dry) through D4 (exceptional drought), as shown in **Table 2-1**.

**Table 2-1. U.S. Drought Monitor Classifications**

| Category | Description | Possible Impacts |
|---|---|---|
| D0 | Abnormally Dry | Going into drought:<br>• Short-term dryness slowing planting, growth of crops or pastures<br>Coming out of drought:<br>• Some lingering water deficits<br>• Pastures or crops not fully recovering |
| D1 | Moderate Drought | • Some damage to crops and pastures<br>• Streams, reservoirs, or wells low, some water shortages developing or imminent<br>• Voluntary water-use restrictions requested |
| D2 | Severe Drought | • Crop or pasture losses likely<br>• Water shortages common<br>• Water restrictions imposed |
| D3 | Extreme Drought | • Major crop/pasture losses<br>• Widespread water shortages or restrictions |
| D4 | Exceptional Drought | • Exceptional and widespread crop/pasture losses<br>• Shortages of water in reservoirs, streams, and wells creating water emergencies |

Source: U.S. Drought Monitor

The USDM uses numeric inputs, including the PDSI, the SPI, and other climatological inputs in addition to expert input and local observers to interpret current conditions and assign a category representing drought intensity. Ground truthing and collecting local information is completed via a network of observers across the country that includes state climatologists, National Weather Service staff, extension agents, and hydrologists (USDM 2021). Available at: https://droughtmonitor.unl.edu/

- **U.S. Agricultural Commodities in Drought:** This weekly map produced by USDA shows the percentage of agricultural commodities being affected by drought. The map is created using USDM and agricultural census data (NDMC 2021c). Available at: https://agindrought.unl.edu/

- **Drought Impact Reporter (DIR):** DIR was developed in 2005 by NDMC and provides a historical archive of drought impacts based mainly on input from stakeholder, government, and media reports, as well as volunteer observations. This interactive database of drought impacts can be searched by location, data, drought type, and cost (NDMC 2021d). Available at: https://droughtreporter.unl.edu/map/

- **Community Collaborative Rain, Hail & Snow Network (CoCoRaHS):** CoCoRaHS is a volunteer network of weather observers that measure and map local precipitation. Daily precipitation maps are updated every 5 minutes, and precipitation summary data is available to compare measurements on various timescales. Condition monitoring data is also collected from observers and is used to create maps and reports used by USDM committees in determining the drought status of areas. Major sponsors include NOAA and the National Science Foundation, and the network is used by a variety of organizations and individuals including NDMC and the National Integrated Drought Information System (NIDIS). Available at: https://www.cocorahs.org/
- **Condition Monitoring Observer Reports (CMOR):** This nationwide service, provided by NDMC in partnership with NIDIS, allows users to report drought-related conditions including photographs. This information then appears on a map and becomes part of a permanent record database. Available at: https://droughtimpacts.unl.edu/ConditionMonitoringObservations.aspx

## 2.3 Drought Impacts

A drought impact is an observable effect or change on human activity or a natural process at a specific time that is directly or indirectly caused by drought. The interaction of the drought event and the exposed elements, such as people, agricultural areas, reservoirs, and water supplies, and the vulnerabilities of these elements to droughts, determines the impacts. Economic, environmental, and social impacts from drought conditions can cause widespread distress. Direct impacts can cause ripple effects resulting in indirect (or secondary) impacts, which must be carefully considered in drought planning and response.

Economic impacts may include impacts to farmers, businesses, and individuals. In cases of severe drought, farmers may lose money because of destroyed crops. In less severe situations, farmers may be forced to spend additional money on irrigation or new groundwater wells. Indirectly, businesses that support farmers or depend on farming, such as agricultural supply companies, may lose business when drought impacts crops or livestock. Furthermore, these expenses may be further passed on to the consumer in the price of food and other agricultural products. Municipal and industrial economic impacts may include additional expenses for water companies or industries to secure additional water supplies. Recreation- and navigation-related industries may also incur loss of business or additional expenses owing to decreased water levels.

There are many environmental impacts that can result from drought conditions. Plant and animal habitat can be destroyed or damaged and disease can increase in wild animals because of lack of food and water supply. In some cases, wildlife may have options for migration to areas with sufficient water supply, but extreme drought can lead to extreme stress or death for plants and animals from inadequate drinking water supply. Landscape-level transitions may occur following a prolonged drought. Drought can also cause decreased water levels in lakes, reservoirs, and streams, as well as loss of wetlands. Decreased reservoir and surface water levels can also lead to increased water temperatures and poor water quality. Susceptibility to wildfire also increases during drought conditions.

Social impacts of drought are those that affect not only changes in lifestyle, but also those that affect health and safety. Social impacts may include reduced incomes, relocating families or businesses to areas with adequate and reliable water supply, and decreased availability of water-based recreational activities. More extreme impacts include stress from economic loss caused by drought, health-related impacts from poor water quality, decreased water availability, and/or poor air quality due to increased dust. There may also be public safety concerns because of increased range and frequency of wildfires. Ultimately, extreme drought conditions can also lead to loss of human life.

A list of potential drought impacts in Missouri for each category of drought is provided in **Table 2-2**. The list, which includes examples of both direct and indirect impacts, does not represent all impacts that result from drought.

**Table 2-2. Potential Drought Impacts in Missouri**

| Economic Impacts | Environmental Impacts | Social Impacts |
|---|---|---|
| • Reduced crop yields or crop loss<br>• Increased consumer cost for certain foods<br>• Increased levels of nitrates in corn, forage, silage, and baleage, limiting their use and supply and increasing costs<br>• Limited hay and water for cattle<br>• Culling livestock<br>• Increased pests and diseases that affect crops, forage, and livestock<br>• Reduced livestock sales<br>• Cost for hauling water and transporting hay for livestock<br>• Increased crop irrigation cost<br>• Cost to develop new water sources, such as drilling new wells, digging existing wells deeper, installing interconnections between systems, installing temporary pipelines, etc.<br>• Tourism and water recreation business declines<br>• Municipal water restrictions cause decreased revenue<br>• Building foundation damage because of dry soil<br>• Reduced water supply for hydropower<br>• Reduced groundwater availability for municipal and agricultural use<br>• Reduced river transportation and increased transportation costs<br>• Reduced manufacturing and closure of manufacturing facilities | • Increased fire threats and wildfire<br>• Reservoir, lake, pond, and river levels decline<br>• Aquifer depletion<br>• Animal stress (e.g., disease) owing to lack of food and drinking water availability<br>• Increased animal mortality<br>• Migration of wildlife<br>• Insect populations decrease or increase<br>• Fish kills due to low flows and/or high stream temperatures<br>• Extinction of local species<br>• Reduced biodiversity<br>• Increased algal growth, lower dissolved oxygen levels, and increased turbidity<br>• Loss of wetlands<br>• Stress to trees, landscaping, and lawns<br>• Forest conversion to non-forested vegetation because of wildfire and insects<br>• Poor soil quality<br>• Wind erosion of soils | • Reduced recreational opportunities<br>• Human health impacts from reduced water quality and quantity<br>• Human health impacts from increased dust and wildfire particulate matter<br>• Stress and other negative mental health outcomes resulting from economic and environmental impacts<br>• Increased risk of disease in drier conditions<br>• Increased mortality rates<br>• Decrease in hunting as animal populations change behaviors and animal mortality rises<br>• Reduced income for individuals in occupations impacted by drought<br>• Increased threat to public safety because of forest and range fires<br>• Human migration from rural areas to urban areas<br>• Conflicts because of lack of water supply |

Understanding and monitoring drought indicators and indices and implementing a robust drought early warning system that triggers early preparedness and mitigation can help reduce the impacts of drought. NIDIS established the Drought Early Warning System (DEWS) program, which uses networks of data and information, to make climate and drought science available for decision-makers. Missouri falls within the overlapping Midwest DEWS and Missouri River Basin DEWS, both of which provide tools and information aimed at improving drought monitoring, forecasting, planning, and preparedness. Assessment of impacts is complicated and is directly related to overall drought exposure and vulnerability. Understanding drought impacts is essential to developing strategies to assist in mitigating future droughts.

## 2.4 History of Drought, Drought Monitoring, and Drought Response in Missouri

The current drought categories used by the USDM were established in 1999 by NDMC and NOAA using a numerical drought classification scale similar to the Fujita Scale for tornadoes and the Saffir-Simpson scale for hurricanes to allow for easier interpretation of drought conditions by the public and to provide a uniform method of comparing droughts (Svoboda et al. 2002). These USDM drought categories have been retroactively applied to historical data by NIDIS, based on the SPI, in an attempt to standardize the analysis of droughts before and after the implementation of the USDM. Therefore, the drought category ratings for droughts prior to 2000 were not created in the same manner as droughts occurring since 2000. Additionally, other drought reporting tools, such as the DIR and the CMOR, have only become available in recent years.

While historical events are not necessarily indicative of future conditions, analysis of past droughts and drought response in Missouri can identify potential impacts of future droughts and help select effective mitigation, monitoring, and response measures. Droughts impacting at least some portion of Missouri are common occurrences throughout recent history and are expected to impact some part of the state every year (Decker and Guinan 2016). Most droughts are short in duration, lasting a few weeks to a few months, but occasionally they are prolonged. The intensity and spatial extent of drought also varies widely between drought events. Severe droughts have been experienced multiple times in the history of Missouri, but there is no convincing evidence they occur with any cyclic regularity (Decker 2018). The following provides a brief history of droughts that have impacted Missouri.

### 2.4.1 Droughts Occurring Prior to 2000 in Missouri

Numerous droughts have occurred in Missouri since official records began in 1895. Based on the historical data available from NOAA/NIDIS, a significant drought started in May 1901 that continued through the summer of 1902 until above-average precipitation brought the state out of drought (although some counties in the Southeast region were still in drought conditions through December 1902). The state average precipitation in 1902 was only 25.86 inches, making it the second driest year on record (Missouri Climate Center 2021b). There were 12 straight months of D4 drought conditions impacting some portion of the state, with 7 of those months (August 1901 to February 1902) affecting more than 50 percent of the state. In January 1902, D4 drought conditions covered 84.9 percent of the state and every county was in some form of drought. The impacts from this drought are difficult to quantify given the available data.

Over the next 30 years, droughts were typically short-term events with more localized impacts. Notable exceptions occurred in 1914 and 1918, when drought impacts had a larger spatial extent, although these were short-term or flash droughts. The Dust Bowl of the 1930s saw widespread drought conditions impacting large portions of the Midwest owing to a combination of drought, high temperatures, and poor farming practices that increased soil loss because of wind erosion. Missouri experienced exceptional drought in 1930 to 1931, 1934, and 1936, with each drought being more severe than the previous in terms of spatial extent, duration, and intensity. Each subsequent drought occurred before the impacted areas could adequately recover, making the next drought occurrence even more severe. The state oscillated in and out of drought from 1936 to 1939 but not to the extent of the droughts earlier in the decade. The final drought event associated with the Dust Bowl in Missouri was the prolonged but low-intensity drought from fall 1939 through summer 1941. The Dust Bowl-era droughts had a significant impact on agriculture across the Midwest and contributed to the severity of the Great Depression. Economic impacts from these droughts are difficult to quantify, but total federal aid across the United States is estimated to have exceeded $1 billion (in 1930s dollars, or $18 billion in 2020 dollars) by the droughts' end (Mid-America Regional Council 2010).

A prolonged, severe drought returned to Missouri from 1952 to 1956, with 1953 being the driest year on record. The state annual average precipitation was only 25.5 inches that year, compared to an annual average of 41 inches (Missouri Climate Center 2021b); 1952 to 1956 is the driest consecutive 5-year period

on record for Missouri since 1895, with a departure from normal of 48 inches of precipitation over that time (Guinan 2019). Analysis of historical SPI data converted to the current drought categories shows 97.1 percent of Missouri was experiencing D4 drought in February 1954.

This drought resulted in significant impacts to agriculture and urban water systems that were exacerbated by high temperatures; the highest temperature ever recorded in Missouri (118 degrees Fahrenheit) occurred on July 14, 1954 (Missouri Climate Center 2021b). Damage to the corn, soybeans, and spring wheat crops was widespread, with some areas reporting total loss of crops. Livestock mortality increased and farmers sold cattle, sheep, and hogs earlier than normal, which caused prices to fall. In mid-July, the United States Senate passed a bill allowing the Farm Credit Administration to make loans to farmers impacted by drought. The Governor, working with farm groups, proposed the federal government provide increased financial assistance and make a disaster declaration for the entire state. The federal government agreed to purchase beef, if necessary, to prevent a price drop, and President Eisenhower eventually declared 81 of the 114 counties in Missouri disaster areas. State and federal grants were made available to transport hay from other states to farmers in Missouri to feed livestock and mitigate the impact of the drought on grazing pastures. Water systems in Kansas City and St. Louis faced severe shortages because of expanding suburbs and infrastructure that could not accommodate the extreme conditions. Outdoor watering restrictions were enacted to help ease the demand and penalties were levied to reduce noncompliance (Westcott 2011).

Analysis of USDM data shows significant droughts also occurred in Missouri from 1963 to 1964, from 1976 to 1977, in 1980, and from 1988 to 1989. These droughts had irregular spatial distributions as opposed to wide-area coverage, meaning that the impacts varied significantly from one area to another. However, by the end of each drought event, substantial portions of the state had been impacted.

The drought of 1988 to 1989, often referred to as the Great Drought, impacted at least 35 states. According to USDM data, the Great Drought brought exceptional drought conditions across northern Missouri and moderate to extreme drought conditions across central Missouri. The city of La Belle in Lewis County experienced the lowest annual precipitation in the last 100 years, with only 14.97 inches recorded in 1988 (Missouri Climate Center 2021b). Extreme and exceptional drought conditions persisted in northeast Missouri well into 1989. Simultaneously, southern Missouri was either not experiencing drought conditions or, in the case of the Southeast region, had above-average precipitation.

In 1989, the State Water Resources Plan required that the Missouri Department of Natural Resources (MoDNR) ensure the quality and quantity of Missouri's water resources be maintained at the highest possible level to support present and future uses by developing a long-range comprehensive plan for the use of surface water and groundwater (MoDNR 2002). Up to that time, drought in Missouri was largely considered a rural problem to be primarily handled by private citizens, industry, or local governments. The 1995 Drought Response Plan acknowledged that drought could have regional or statewide implications and established the Drought Assessment Committee (DAC) to coordinate a drought response effort during future drought events. Additionally, improvements were made to precipitation measurements, streamflow observations, groundwater level monitoring, and reservoir operation modeling. When the DAC was first activated in July 1999, emergency conservation reserve lands and alternative water supplies were made available for livestock and agricultural needs (Westcott 2011).

### 2.4.2 Droughts Occurring Since 2000 in Missouri

The USDM has assigned drought categories at various spatial resolutions since 2000. Data is available for the entire United States, individual states, counties, climate regions, climate divisions, Federal Emergency Management Agency regions, and several other area types. The historical drought conditions in Missouri since 2000 are shown in **Figure 2-6**. The drought of 2012 was the most intense drought to impact Missouri since the USDM began categorizing drought on a weekly basis. The longest period of drought (D1 to D4) in

Missouri since 2000 began in July 2002 and ended in May 2004, for a total of 99 weeks in drought (NIDIS 2021).

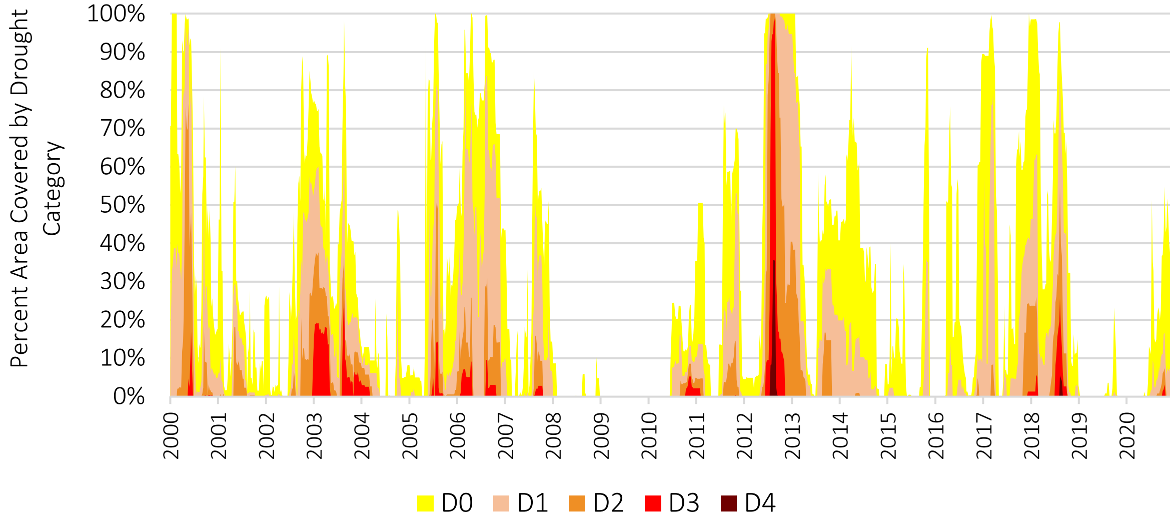


**Figure 2-6. Percent of Area in Missouri in Each Drought Category, 2000–2020**
*Source: USDM*

A new method introduced by the USDM for analyzing drought data is the Drought Severity and Coverage Index (DSCI), which converts drought levels from the USDM to a single numerical value for a given geographic area (e.g., state, county, climate division). Using the DSCI provides a convenient way to transform USDM data from categorical to continuous, and to aggregate data based on political boundaries (Akyuz 2017). The DSCI can be calculated using categorical data and applying the following formula using the percentage of area covered by each drought category:

$$(1 \times \mathrm{D0}) + (2 \times \mathrm{D1}) + (3 \times \mathrm{D2}) + (4 \times \mathrm{D3}) + (5 \times \mathrm{D4}) = \mathrm{DSCI}$$

The DSCI was calculated for each county using historical monthly data from NIDIS for 1895 to 2020 based on SPI data converted to USDM drought categories. This methodology was selected due to USDM drought data only being available since 2000 and to ensure a consistent methodology was applied to the entire historical data set available for Missouri. The resulting monthly DSCI values were averaged for 1895 to 2020, as shown in **Figure 2-7**, and indicate counties in the West Central and Central regions had the highest drought severity and coverage over the last 125 years. The data also shows that counties in the Southeast and South Central regions had lower drought severity and coverage over the period of available data.

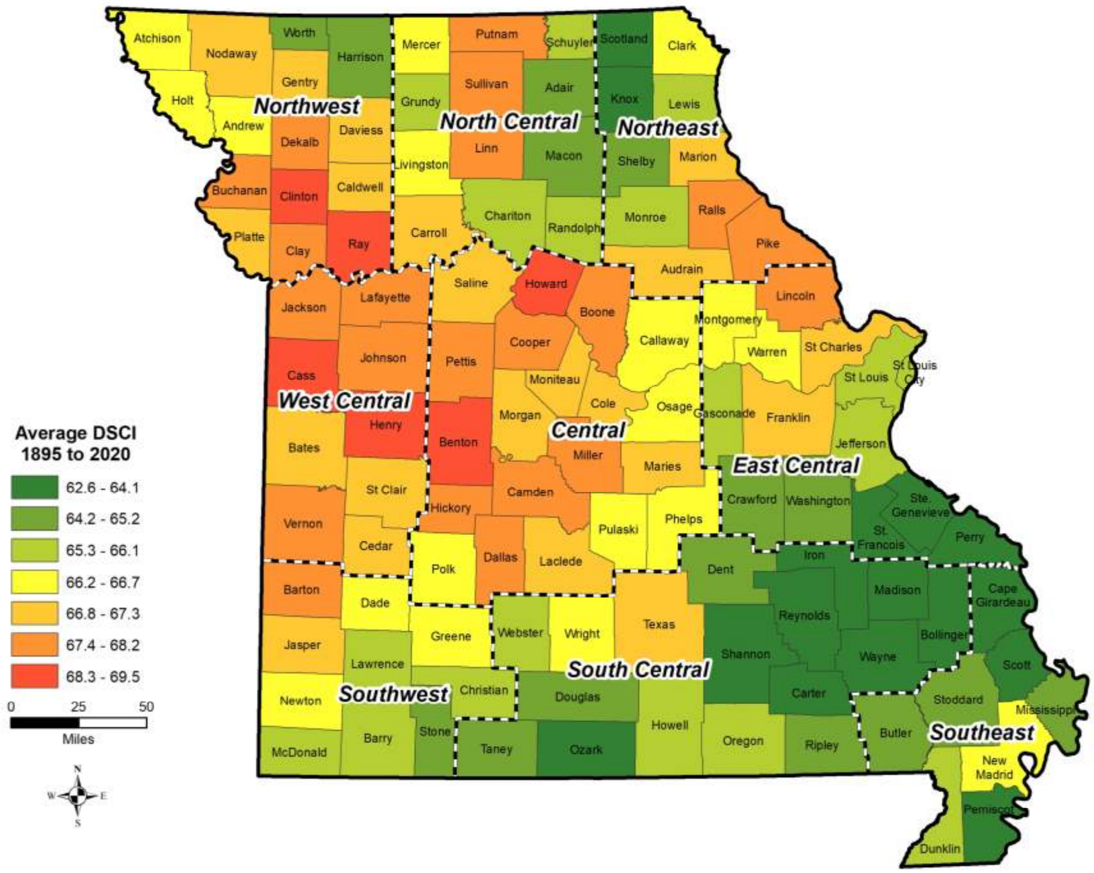


**Figure 2-7. Average Monthly DSCI by County, 1895–2020**
*Source: NIDIS*

Analyzing NIDIS data over different timescales results in different spatial pattern and ranges of DSCI values compared to using the entire period of record. As shown in **Figure 2-8**, the average DSCI from 1895 to 1990 excluding the most recent 30-year period is significantly different in spatial distribution from the average DSCI from 1895 to 2020 and has a larger range of values. Notable differences include the Northwest region being the least impacted by drought over that time, while the Central and East Central regions were the most impacted.

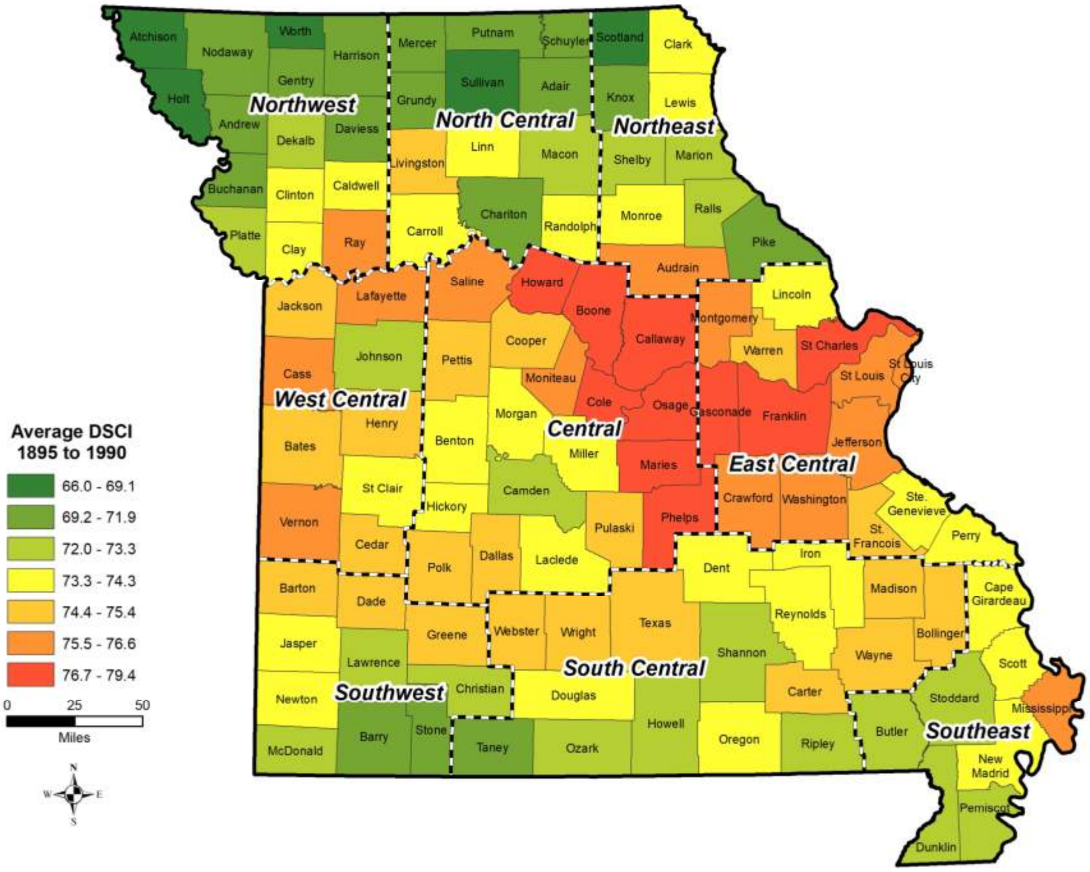


**Figure 2-8. Average Monthly DSCI by County, 1895–1990**
*Source: NIDIS*

Conversely, the average DSCI over the previous 30 years is highest in counties within the Northwest and North Central regions, as shown in **Figure 2-9**, while counties in the East Central, South Central, and Southeast regions have the lowest level of drought severity and coverage. The average DSCI over the previous 30 years also reflects a spatial pattern similar to that of the 30-year average annual precipitation, with increasing precipitation from northwest to southeast.

**Appendix A** includes a series of 12 maps depicting the average DSCI by county for each decade since 1900. The average DSCI scale is kept consistent on each map to allow for comparison between decades. When evaluated by decade, the average DSCI maps highlight the fact that the droughts of the 1930s and 1950s were the most severe and widespread. Even with the droughts of 2012 and 2018 (which are discussed below), the most recent decade shows relatively low average DSCIs. Only the 1920s and 1990s appear to have lower average DSCIs (lower drought extent and severity) than the 2010s.

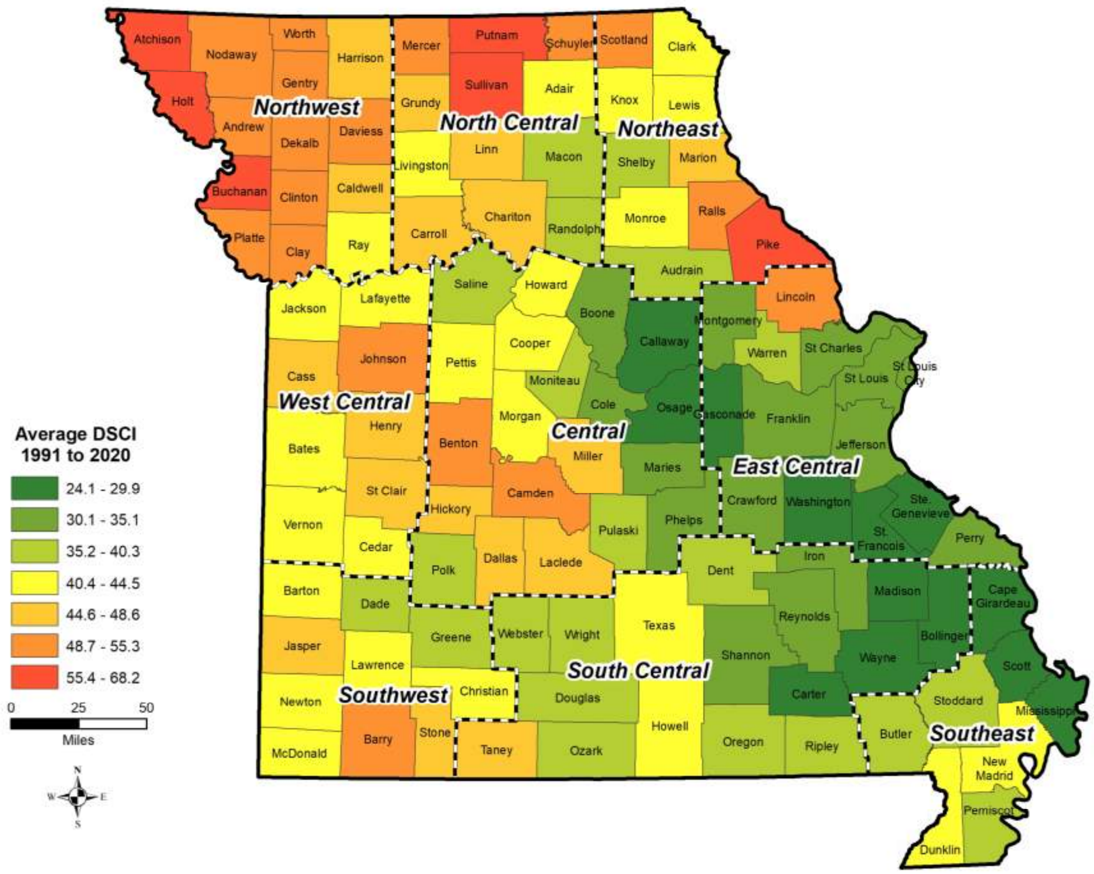


**Figure 2-9. Average Monthly DSCI by County, 1991–2020**
*Source: NIDIS*

Historical USDM drought data was analyzed based on percent of time in drought, consecutive weeks in drought, and nonconsecutive weeks in drought at the county level. A county was determined to be in drought for a given week if 0.01 percent of the county was in D1 or worse drought conditions. This is the threshold value the USDA uses when applying USDM data to their programs (Fuchs 2021). Likewise, consecutive and nonconsecutive weeks in drought are determined by the USDM based on the same threshold value of 0.01 percent of area within a county. The percent of time in drought, as shown in **Figure 2-10**, has a similar pattern as the DSCI by county over the last 30 years and indicates that some counties in the Northwest and Northeast regions have spent nearly twice as much time in drought as counties in the East Central and Southeast regions.

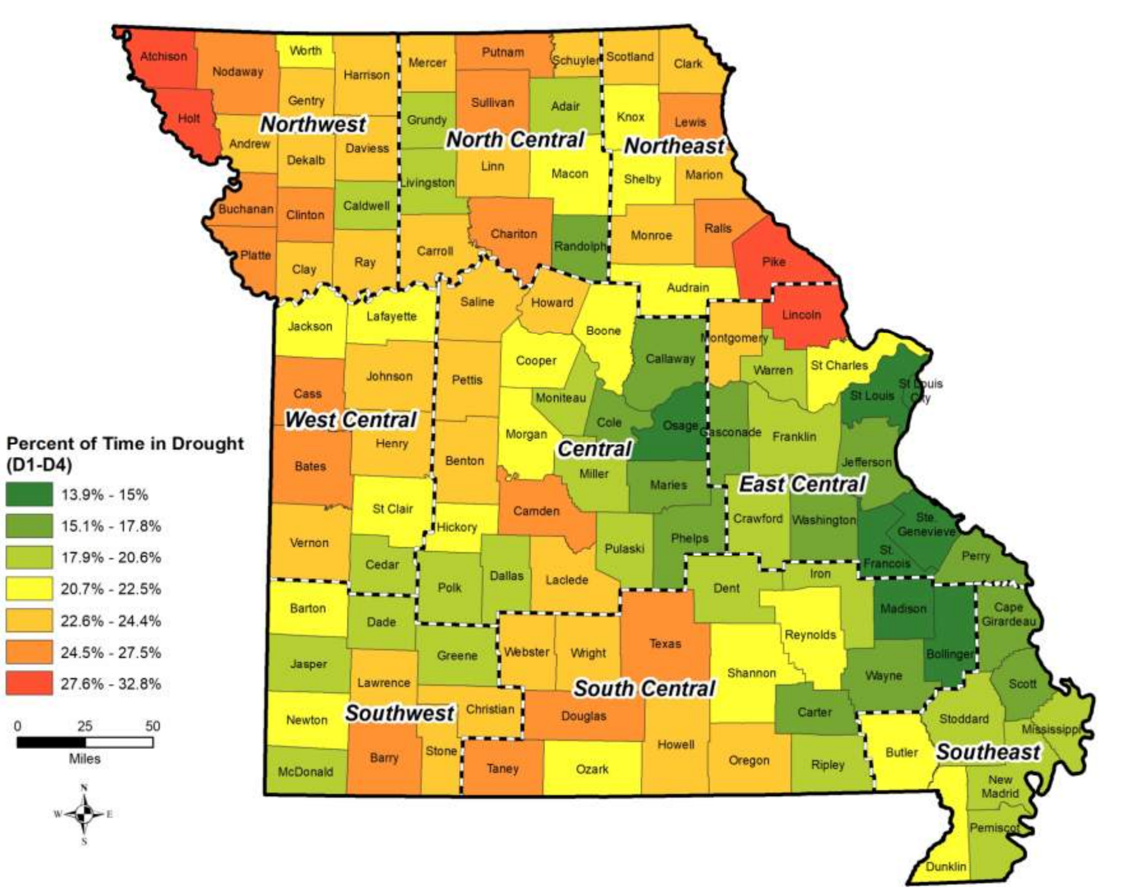


**Figure 2-10. Percent of Time in Drought by County, 1991–2020**
*Source: NIDIS*

The data for consecutive and nonconsecutive weeks in drought is useful information but difficult to aggregate and present in a concise, clear method since data is separated by drought category. However, the data generally presents the same pattern as the climate division level data in that counties in the Northwest typically have the highest number of consecutive and nonconsecutive weeks in drought based on all drought category levels. One notable difference is that counties in the Southeast region rank relatively high in comparison to other counties for average number of consecutive weeks in drought at the D3 and D4 levels, mainly because of the 2012 drought that resulted in the Southeast region experiencing exceptional and extreme drought conditions.

The droughts of 2012 and 2018 were the most significant drought events in the last 30 years in Missouri. A brief history of each drought is presented in more detail in the following subsections.

### 2.4.3 Drought of 2012

The 2012 drought was the worst drought impacting Missouri since the Great Drought of 1988 to 1989, and one of the worst droughts since the drought of record in the 1950s. The 2012 drought was preceded by an unusually dry winter, and large portions of the state had only just come out of abnormally dry to moderate drought conditions from the prior year. Drought conditions began in the Southeast region in May before expanding across the entire state within a few weeks. The quick onset of the drought and rapidly deteriorating conditions classify this event as a flash drought. This type of drought increases the difficulty of mitigating the impacts because of the lack of time to respond. **Figure 2-11** provides a timeline of the 2012 drought and the following paragraphs summarize the impacts and response.

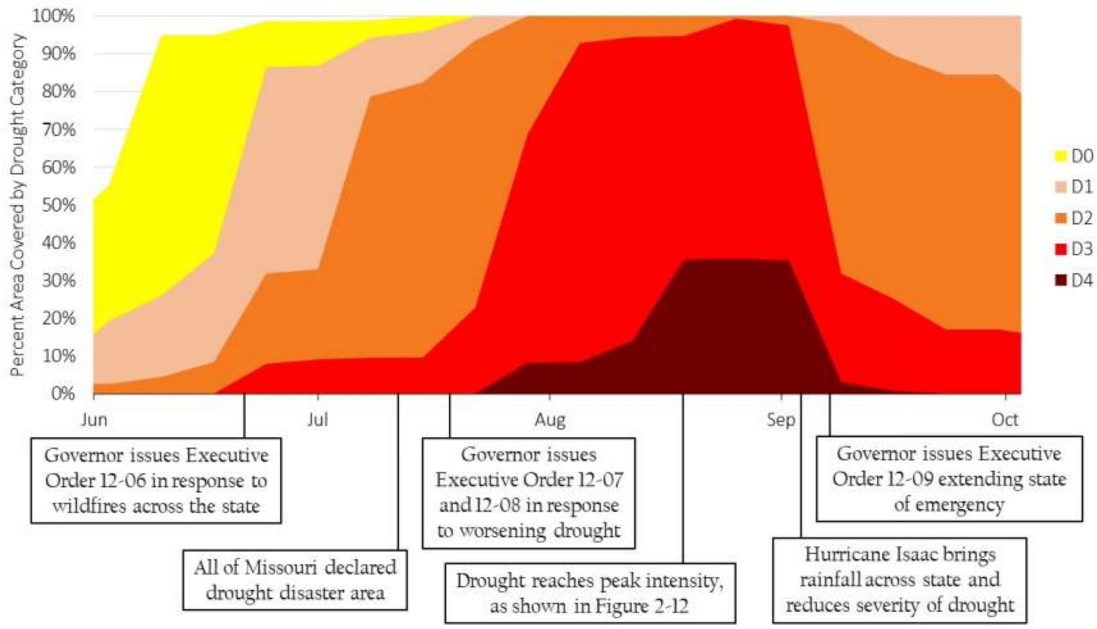


**Figure 2-11. Timeline of the 2012 Drought**

On June 29, 2012, in response to severe heat, dry conditions, and fire risks, Governor Nixon issued Executive Order (EO) 12-06. The EO directed the State Emergency Management Agency, the state fire marshal, and other state agencies to help coordinate resources and responses with local authorities. The Missouri National Guard was also ordered to ready personnel and supplies to support firefighting operations if needed (Missouri Secretary of State 2012a). By that time, over 600 acres had burned in the Mark Twain National Forest and 100 acres were actively burning (MoDNR 2013). EO 12-06 was set to expire on July 29, 2012, unless extended in part or in whole.

On July 10, 2012, Governor Nixon requested a statewide disaster assessment, a prerequisite to a disaster declaration, and on July 12, the first counties in Missouri began receiving disaster declarations. An agricultural disaster declaration may be issued by the President of the United States or the Secretary of Agriculture and recognizes a loss of at least 30 percent of production of at least one crop in a county or for a producer. Eligible farmers can then be considered for assistance, such as loans from the Farm Service Agency (FSA). All 114 counties in Missouri were declared drought disaster areas within the next week, making Missouri the first state to receive a statewide designation for drought in 2012. Few USDA programs were available at the time to assist growers, livestock producers, and farming communities. The Soil and Water Districts Commission was urged to take emergency action to allow producers to use livestock exclusion areas under contract for grazing, haying, and watering (MoDNR 2013).

Continuing drought conditions led Governor Nixon to issue EO 12-07 and EO 12-08 on July 23, 2012. EO 12-07 declared a state of emergency that activated the Missouri State Emergency Operations Plan, designated additional resources be made available to those affected, and extended EO 12-06 to October 1, 2012 (Missouri Secretary of State 2012b). EO 12-08 authorized the Soil and Water Districts Commission to implement an emergency cost-sharing program for farmers to drill or deepen wells or to expand watering systems. EO 12-08 also established an Agriculture Water Resource Technical Review Team that was responsible for assisting in the expedited processing of applications and implementation of the emergency cost-sharing program. Any completed application not acted upon by a local soil and water district within 72 hours of receipt would be immediately forwarded to the Agriculture Water Resource Technical Review Team for approval or denial. All projects approved under the cost-sharing program were required to be

completed within 60 days of the issuance of the EO. The cost-sharing rate was set at 90 percent with a maximum award of $20,000 (Missouri Secretary of State 2012c). The Soil and Water Districts Commission approved $2 million for the cost-sharing program initially and shortly thereafter, Governor Nixon directed an additional $5 million into the program. The commission increased funding by an additional $4.8 million on July 26, which brought the total cost-sharing program funding to $11.8 million (MoDNR 2013).

Additional response measures included the Governor instructing the Department of Social Services to redirect $1.5 million in Low-Income Home Energy Assistance Program funds to assist low-income Missourians with cooling costs. Governor Nixon urged crisis centers across the state to address suicide prevention in farming communities owing to increased stress caused by drought conditions (NDMC 2012). MoDNR's Public Drinking Water Branch coordinated with regional offices to survey every public water system in the state to assess the impacts of the drought. MoDNR used the results of the survey to develop a list of water systems concerned with drought to allow for prioritization of assistance and mitigation efforts. The Department of Agriculture's online hay directory, which is available year-round, connects buyers and sellers in Missouri and eight surrounding states; this resource was further promoted during the drought as a mitigation tool with the University of Missouri's Cooperative Extension Service providing outreach efforts to producers and rural communities. The Missouri Cattlemen's Association also developed a pasture- and hay-sharing network on their website (MoDNR 2013).

> The quick onset of the 2012 flash drought and rapidly deteriorating conditions increased the difficulty in forging an effective response, and emphasizes the need for effective forecasting, monitoring and predrought mitigation actions and strategies.

By the end of July 2012, Missouri had the worst conditions for corn, soybeans, and pastures in the nation according to the National Agricultural Statistics Service. The period of May through July was the third warmest and third driest on record. In response, the Missouri Department of Agriculture requested, and was granted, approval from Missouri Department of Transportation (MoDOT) for farmers to haul overweight loads of silage and baleage on highways over concerns that hay shortages might increase. Heavier grain loads were allowed during harvest as well, because of low water levels on the Missouri and Mississippi rivers that limited grain movement by barge. By August 2, 2012, the USDM reported that 93 percent of the state was in extreme drought—a significant increase from the prior week when 69 percent of the state was in extreme drought. On August 21, the Soil and Water Districts Commission voted to approve splitting the remaining cost-sharing program costs equally with other state funding sources, which increased the total amount of available funds.

The week of August 21 saw the drought peak in severity, with 35.7 percent of Missouri experiencing D4 drought conditions and 63.6 percent of the state in D3 drought conditions, as shown in **Figure 2-12**. The USDA stated that 99 percent of Missouri pastures were in poor or very poor condition. Hay and other roughages were rated 90 percent inadequate (short) and stock water supplies were rated 94 percent inadequate (short). Crops were also suffering as 85 percent of corn and 78 percent of soybeans were rated poor to very poor.

On August 27, the Governor announced the cost-sharing program review and approval process had been completed. Interest in the program was higher than anticipated and increased the cost to roughly $29 million, as the state approved 5,885 applications with an average project cost of over $4,800. The highest number of emergency cost-sharing projects approved were in the Central, West Central, South Central, and Southwest regions. These same regions had the highest number of projects to drill new wells or deepen existing wells. The West Central, Southwest, and South Central regions had the highest total dollar amount of approved projects by county, followed by the East Central region, because the majority of livestock and poultry farms in the state were in these regions. Projects that connected customers to public water systems

mainly occurred in the Northwest, North Central, Northeast, Central, and West Central regions because of the lack of groundwater suitable for use. Eight public water districts did not accept additional service connections owing to supply capacity and infrastructure issues. Additionally, EO 12-08 required that water projects not adversely affect public water supplies. Governor Nixon issued EO 12-09 on September 10, which extended the state of emergency to November 15, owing to heat, fire risk, and prolonged drought. Cost-sharing program participants were also given more time to complete projects. The EO established a Program Audit and Compliance Team to ensure program accountability (Missouri Secretary of State 2012d).

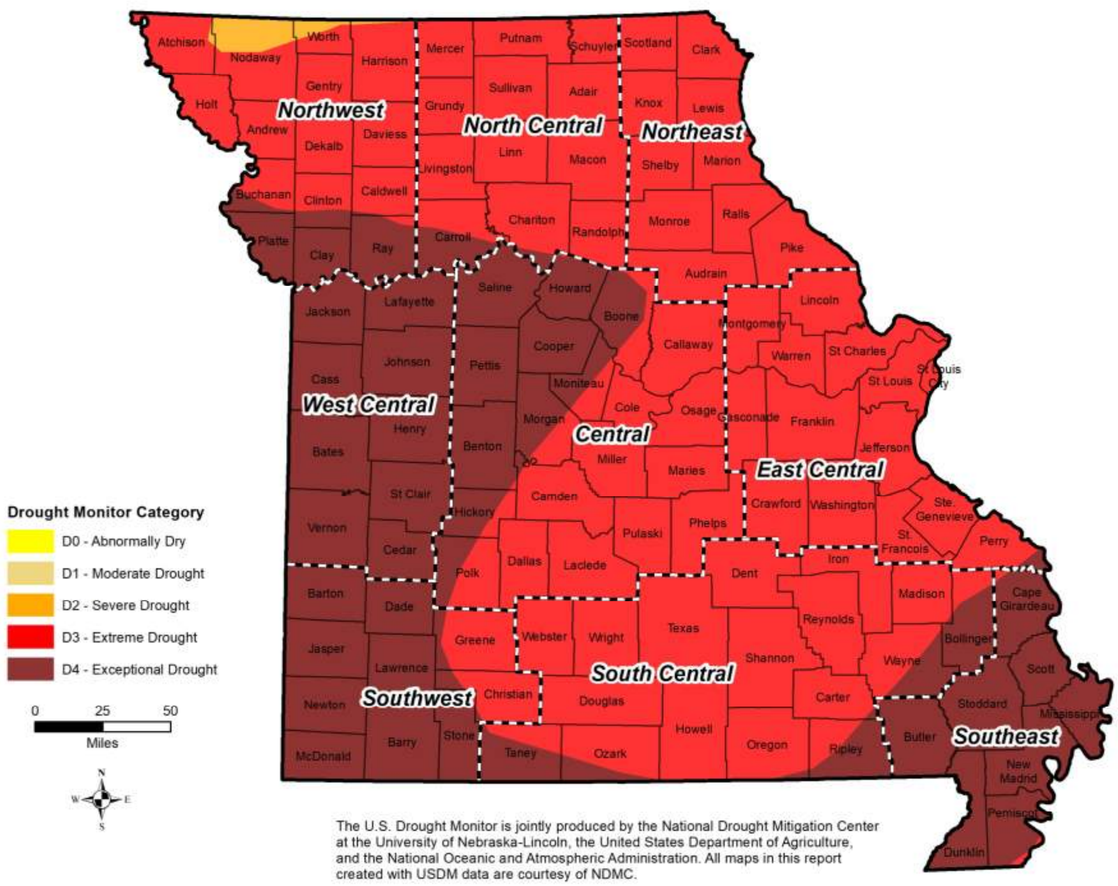


**Figure 2-12. Drought Conditions During the Week of August 21, 2012**
*Source: USDM*

The extreme and exceptional drought conditions began to subside as the remnants of Hurricane Isaac moved across southern Missouri on August 30, 2012, bringing rain to the rest of the state over the Labor Day weekend. However, severe and moderate drought conditions lingered through the fall and into early spring 2013 for most of the state (MoDNR 2013).

Average statewide precipitation from June to August 2012 was 5.97 inches, making it the third driest summer on record and the driest since 1953. During this same time, St. Louis experienced 61 out of 92 days when temperatures exceeded 90 degrees Fahrenheit (MoDNR 2013). According to the DIR, extreme heat and drought threatened wildlife and burn bans were implemented in all conservation areas across the state. Public water supplies faced supply shortages that prompted voluntary and mandatory water conservation orders across the state. In the city of Warrenton, the groundwater level dropped so low that the pump inlet

was exposed in a supply well, causing damage to equipment and loss of production. Low water levels on the Mississippi River forced the Associated Electric Cooperative to deploy diesel powered pumps to supply water to the New Madrid Power Plant to maintain electricity supply to approximately 660,000 homes, farms, and businesses. Use of the diesel pumps maintained the operation of the power plant but significantly increased costs at a time when financial strain on farmers was already causing widespread hardship (MoDNR 2013).

While the exact economic impact on Missouri from the 2012 drought is difficult to ascertain because of the broad nature of drought impacts, estimated losses to livestock and poultry operations exceeded $547 million when accounting for increased feed costs, changes to livestock sales and inventory, and livestock mortality in 2012 and 2013, according to University of Missouri economist Ron Plain (MoDNR 2013). Many farmers were forced to sell livestock to reduce operating costs; however, most livestock were underweight because of the drought and prices were suppressed by the increased supply for sale. Nearly 100 dairy operations closed during 2012 according to Dave Drennan, Executive Director for the Missouri Dairy Association (NDMC 2012).

The federal government response to the drought of 2012 included USDA taking several administrative actions, such as reducing the interest rate for emergency loans from 3.75 to 2.25 percent, making larger payments to producers using Conservation Reserve Program (CRP) lands for emergency haying and grazing than under normal circumstances, and announcing the purchase of up to $170 million in livestock and fish products to help alleviate the financial impacts of drought on meat and catfish producers. The U.S. Army Corps of Engineers (USACE) took emergency actions such as blasting rocks in shallow river areas to avoid disruptions to inland waterway navigation. Potential disruptions to Mississippi River barge traffic resulted in increased interest among Mississippi River stakeholders in having federal infrastructure on the Missouri River and its tributaries operated to support Mississippi River navigation. The intensifying interest of Mississippi River stakeholders added to the challenge USACE experienced in balancing the needs of a diverse mix of basin stakeholders that included agricultural, municipal, and industrial water supply users; hydropower users; navigational interests; and ecological considerations for species that rely on certain water flows and the timing of water releases (Folger et al. 2013).

### 2.4.4 Drought of 2018

The 2018 drought was the second worst drought impacting Missouri since the Great Drought. While during the flash drought of 2012 a higher percent of the state experienced extreme and exceptional drought conditions, the 2018 drought lasted longer and caused significant impacts. The drought began in fall 2017 as periods of abnormally dry and moderate drought conditions occurred across much of eastern Missouri resulting from below-average precipitation since May 2017. Severe drought conditions began to appear across the South Central and East Central regions by December 2017, while abnormally dry and moderate drought conditions expanded to western portions of the state. The drought continued to expand and almost the entire state was in some form of drought condition by February 2018. The eastern portion of the state saw some relief in March, April, and May 2018, while the western portion continued to experience abnormally dry to moderate drought conditions. However, drought conditions returned to much of the state by summer 2018 and lasted through that fall. **Figure 2-13** provides a timeline of the 2018 drought and the following paragraphs summarize the impacts and response.

The Missouri Drought Response Plan in effect during 2018 called for the formation of a Climate and Weather Committee (CWC) to monitor climatic conditions as drought began to emerge within the state. The committee first met on January 29, 2018, to discuss dry conditions over the previous months and early preparations should the drought persist into the growing season. Precipitation in early spring 2018 reduced concerns of drought, but extreme fluctuations in monthly temperature occurred between April and May; April was the second coldest on record and May was the warmest on record since 1895 (Guinan 2019).

Below-average precipitation in May combined with above-average temperatures resulted in high rates of ET and soil moisture depletion. Pastures and crops were stunted by the extreme temperature fluctuations and lack of available moisture in the soil. The USDM indicated that 18.75 percent of the state was experiencing some form of drought (D1 to D4) by the first week of June. The CWC met again on June 7, 2018, to discuss the existing conditions while noting that continued hot and dry conditions could lead to a quick progression of drought conditions across the state. The CWC met for a third time on July 13, 2018, as conditions continued to deteriorate rapidly. Extreme and severe drought conditions were seen across the Northwest and North Central regions and severe to moderate drought conditions occurred across most of the northern and western portions of the state. The committee recommended that the state enter Phase 2 of the Drought Response Plan and requested that Governor Parson issue an EO declaring a drought in affected areas of the state (MoDNR 2019).

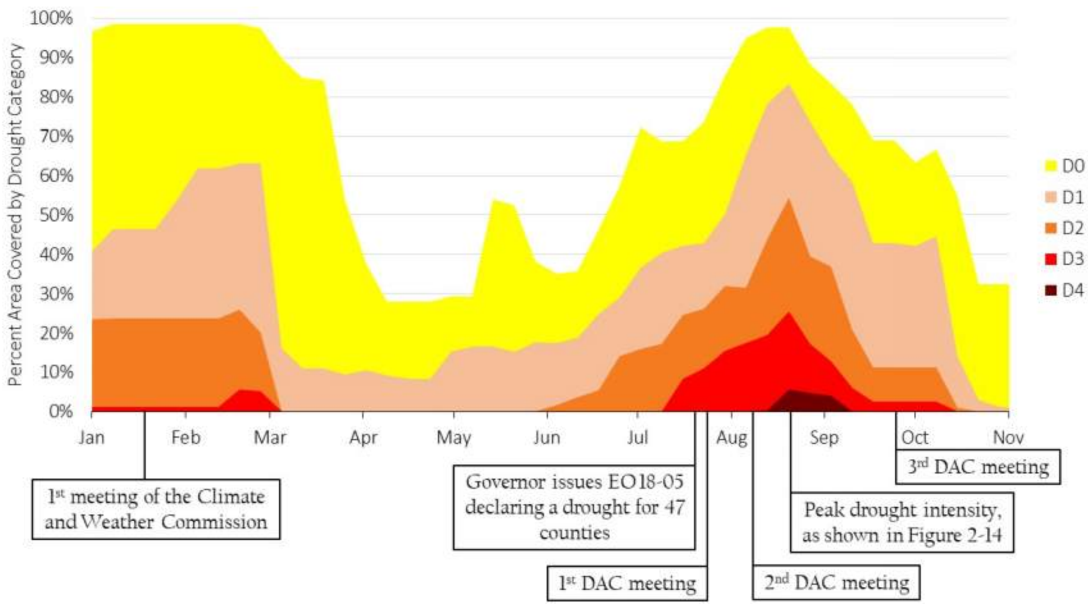


**Figure 2-13. Timeline of the 2018 Drought**

Governor Parson issued EO 18-05 on July 18, 2018, declaring a drought alert for all 47 counties experiencing severe, extreme, or exceptional drought and counties with the potential to enter drought conditions in the near future. The EO directed MoDNR to activate and designate a chair for the DAC and requested state and federal agencies participate as needed. State agencies were also directed to examine how they could assist affected communities and communities that may be impacted in the future through temporary suspension of administrative rules, appropriation, or other means of support to mitigate the effects of the drought conditions (Missouri Secretary of State 2018). In response, the Soil and Water Districts Commission approved changes to policies for cover crop funding, grazing contracts, and grazing in livestock exclusion areas (and created a new program for pond cleanout), providing over $8,150,000 in funding to Missouri landowners (MoDNR 2019).

The first meeting of the DAC was held on July 26, 2018, to provide background information about the existing drought to the committee members and share initial resources available to communities already impacted by drought. Two separate impact teams were formed to assess the impacts on agriculture and public water supplies with the purpose of sharing information with the DAC at subsequent meetings. Pat Guinan, the state climatologist, announced the launch of the Missouri-specific Drought Conditions and Impacts reporting tool hosted by NDMC through the CMOR system. This reporting tool allowed any person to report impacts observed from drought and upload pictures of local drought conditions. There

were 1,488 reports and nearly 200 photos submitted through the CMOR system for Missouri during the 2018 drought (MoDNR 2019).

The DAC met again on August 8, 2018, to continue coordinating resources among state and local agencies. The public water systems for Cameron, Hamilton (in the Northwest region), and the North Central Missouri Regional Water Commission were discussed because of their potential for requiring emergency action if drought conditions continued. Impacts to agriculture and livestock producers were also discussed. MoDOT announced it would issue over-width permits free of charge to aid in transporting hay throughout the state. Governor Parson announced the availability of additional water and hay resources on August 20 in response to the DAC meeting; up to 5,000 gallons of water a day was made available per family farm for livestock at 28 Missouri Department of Conservation (MDC) areas and 5 MoDNR state parks, while a hay lottery was created for farmers to allow haying on 900 acres of Missouri State Parks free of charge. MDC also allowed haying on 474 acres of Conservation Area land (MoDNR 2019). According to the DIR, hay prices reached $150 per ton, which was higher than during the drought of 2012, owing to Missouri producing the lowest amount of hay since the Great Drought of 1988 to 1989.

Governor Parson also announced that over $77,000 in state funds would be made immediately available to assist two public water systems impacted by drought and $912,568 made available in the form of MoDNR emergency grants for 10 eligible projects that submitted applications for assistance. Eight of the 10 projects eligible for emergency grants were cofunded with Missouri Department of Economic Development's Community Development Block Grants, which increased funding by an additional $2,678,608 (MoDNR 2019).

At the peak of drought severity the week of August 14, 2018, 83.3 percent of Missouri was in some form of drought (D1 to D4); 5.5 percent of Missouri was experiencing D4 drought conditions and 19.9 percent was experiencing D3 drought conditions, as shown in **Figure 2-14**. The most intense drought conditions, ranging from severe to exceptional, occurred in the Northwest, North Central, and Central regions, with the Southwest region also experiencing severe to extreme drought.

Weather conditions changed shortly after the drought reached peak intensity and significant rainfall over the subsequent weeks alleviated the exceptional and extreme drought conditions across northern Missouri. Drought conditions continued to improve throughout September 2018, but some localized extreme and severe drought conditions remained. A final DAC meeting was held on September 27, 2018, to discuss the short-term relief in drought conditions from recent precipitation and the need to continue to monitor the long-term hydrological drought conditions that remained across the state. Existing drought conditions continued to improve, and only 1 percent of Missouri remained in moderate drought by the end of October 2018. Some northern counties reported rainfall of 20 to 25 inches from mid-August to mid-October, which was close to the total precipitation from the prior 12-month period (MoDNR 2019).

Federal agencies provided assistance mainly in the form of additional funding for farmers. USDA's Natural Resources Conservation Service (NRCS) announced a modification to the Environmental Quality Incentive Program that provided $2 million in funds to plant cover crops to address inadequate feed, forage, and other natural resource concerns resulting from drought. The modification allowed farmers to use the cover crops for grazing and haying whereas previously only grazing was allowed. NRCS received 1,525 applications for assistance that covered more than 206,000 acres of Missouri farmland, which would have cost $13,400,000 to fully fund had funding been available. Missouri NRCS was granted an additional $2 million from the national office, for a total of $4 million in program funds awarded to 489 properties covering approximately 66,000 acres.

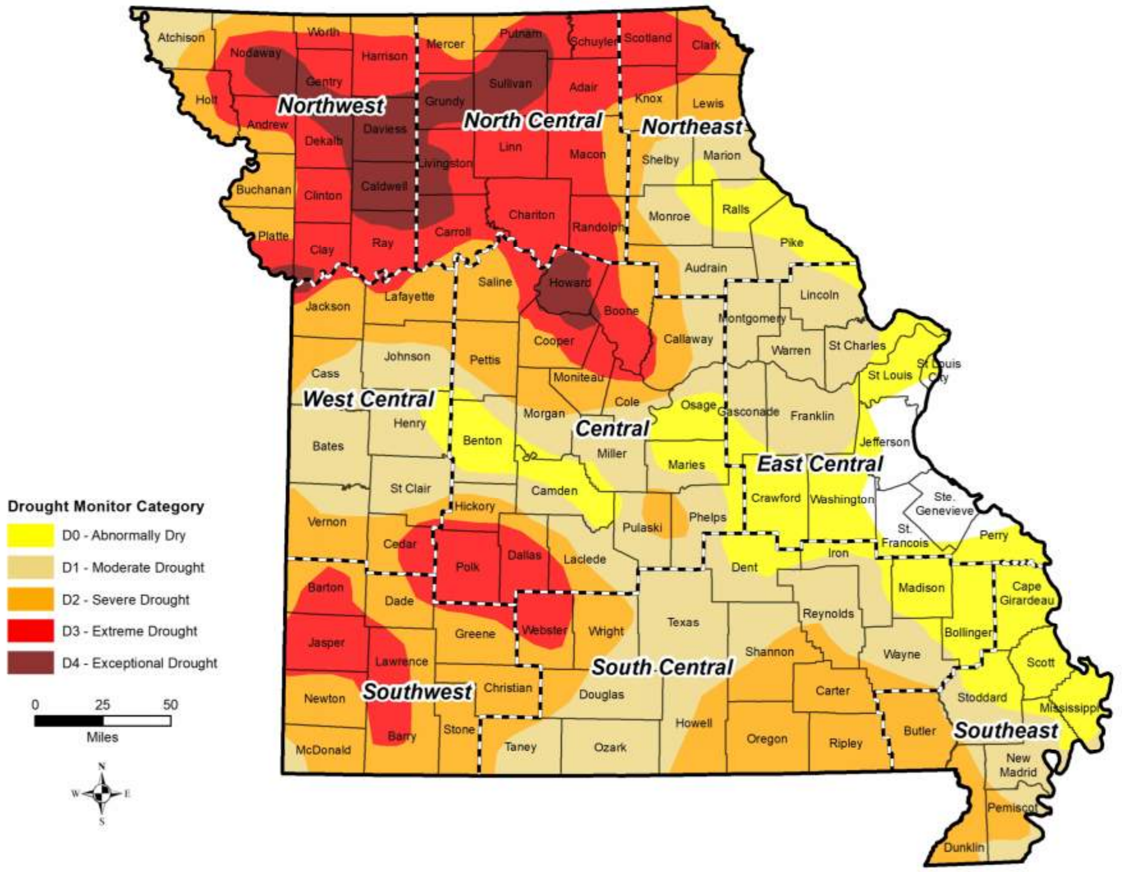


**Figure 2-14. Drought Conditions During the Week of August 14, 2018**
*Source: USDM*

NRCS also allowed landowners to cut hay on 50 percent of grassy areas within their wetland easements in counties experiencing severe or extreme drought conditions. NRCS eventually expanded the number of counties for which additional easement areas were eligible, and an estimated 15,000 acres of grassy area was eventually made available for haying (MoDNR 2019).

FSA offered disaster assistance and low-interest loan programs to assist agricultural producers impacted by drought, including the Livestock Forage Disaster Program (LFP); Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish Program (ELAP); Emergency Loan Program; Noninsured Crop Disaster Assistance Program; Emergency Conservation Program (ECP); and CRP Emergency Haying and Grazing Component. There were 61 counties in Missouri eligible for the LFP and ELAP, 32 counties eligible for an estimated $2 million in ECP funds, and 58 counties eligible for CRP emergency haying and grazing approval (MoDNR 2019).

The drought of 2018 was notably different from the flash drought of 2012 in several ways, including the spatial extent, the timescale on which the drought occurred, and the overall impacts to Missouri. While the drought of 2012 had extreme and exceptional conditions over large portions of the state, the impacts from the drought in 2018 were more localized in certain counties and regions. However, large portions of the state still experienced severe or moderate drought in 2018. Furthermore, the drought was significantly longer than the drought of 2012, which resulted in compounding impacts over time. Prices for hay were higher in 2018 than in 2012 because of the length of the drought; pastures were unable to recover and subsequent growing

The drought of 2018 was notably different from the drought of 2012 in several ways, including the spatial extent (more localized) and the timescale on which the drought occurred (longer).

seasons required an increasing amount of hay to be purchased to compensate for the poor conditions of pastures. The amount of time and precipitation necessary to alleviate the drought was also much greater than in 2012 owing to the prolonged moisture deficit.

As previously noted, the CMOR service was launched in 2018 by NDMC. Reports could be submitted by members of the public and could include pictures of local drought conditions. These reports and pictures serve as useful examples of potential impacts from drought and form a historical database as more reports are collected over time. Examples of user-submitted reports from the drought of 2018 were collected and are presented below.

The most common photos uploaded to the CMOR website show dry pastures and grasslands. **Figure 2-15** shows a picture uploaded on August 5, 2018, with an area of a resident's property where greywater runoff was keeping grass in healthy condition directly adjacent to grass receiving no supplemental water. The drought-stricken grass shown in the picture was representative of their entire 1,000-acre ranch in Texas County.

Other commonly uploaded photos included ponds with low water levels, as shown in **Figure 2-16**. The user commented that their pond was drying up, forcing them to haul water from another location. They also commented that the drought had resulted in no regrowth for the fall pasture. Another photo taken in Linn County shows a pond with a low water level, which included a comment that no surface runoff from rain had been experienced since fall 2017, resulting in extremely low (if any) water levels in ponds and very poor water quality.

**Figure 2-15. Drought Conditions in Texas County, August 2018**
*Source: CMOR*

While some photos uploaded to the CMOR website are not particularly noteworthy, the accompanying details included by the user can be insightful. For example, a farmer in Johnson County remarked in August 2018 that "the creek and pond is dry, which has never happened since renting the pasture 5 years ago. Grass is gone—we've been feeding hay and hauling water to cattle for 3 weeks. To make it worse, hay production is half of normal, there's very little hay available locally, and…[it] is outrageously high priced. I've bought pretty much all we can afford. We're going to have to decrease our herd to match the hay available through winter and that reduction number depends on how much we end up feeding now." Other noted impacts included increased fertilizer application yet insufficient hay production, soybeans and corn underdeveloped or dying, apparent permanent loss of pasture fescue and orchard grass, total loss of a haskap berry orchard, and other tree species experiencing stress, including premature foliage color changes.

Some of the photos uploaded by the users present a compelling story. An example of this is shown in **Figure 2-17**, where a livestock producer has set up a tent, protein tub, and water bowl to mitigate the impacts of heat and low moisture on their livestock.

**Figure 2-16. Low Pond Water Level in Adair County, July 2018**
*Source: CMOR*

The photos and text descriptions uploaded to the CMOR website help illustrate the specific challenges created by drought conditions. Based on the information provided by CMOR, the greatest challenges facing farmers and livestock producers in Missouri during times of drought are availability of surface water, insufficient pasture and grassland to sustain livestock, increased prices for hay, low-yielding crops, and damage to crops during critical growth stages. This results in impacts to livestock such as earlier-than-planned sales, decreased prices at market/auction, and below-average weight. Farmers can experience financial losses if significant quantities of crops are damaged or if the cost of pumping supplemental irrigation exceeds the amount received for their crops.

## 2.5 General Mitigation, Assessment, and Response Options

Drought plans, especially those developed at the state level, have historically focused on drought monitoring and response. In recent years, drought plans have also begun to identify, evaluate, and recommend actions and strategies that can be implemented prior to drought occurring to enhance resiliency and reduce or eliminate the impacts. There has also been an increasing emphasis on actions that assess impacts from drought to aid in the selection of appropriate response options. The Missouri Drought Mitigation and Response Plan considers all actions and strategies—with a focus on those initiated at the state level—that can be made (1) prior to drought, to avoid or reduce potential impacts; (2) as drought is occurring, to identify impacts and assess their severity; and (3) in response to drought. Drought mitigation, assessment and response actions are introduced and organized in Section 6 of this plan according to these three categories. **Table 2-3** further defines these three categories of drought management strategies and provides specific examples.

**Figure 2-17. Mitigation Measures for Livestock in Polk County, August 2018**
*Source: CMOR*

**Table 2-3. Drought Management Strategy Categories and Examples**

| Mitigation Programs | Impact Assessment | Response Programs |
|---|---|---|
| **Mitigation programs** include actions and strategies performed before a drought occurs. These programs focus on reducing or avoiding the impacts from drought, increasing resilience, and/or lessening drought vulnerability.<br><br>**Examples that may be initiated at the state level include:**<br>• Provide conservation and water efficiency technical assistance<br>• Provide or prioritize funding for implementing water conservation programs<br>• Provide or prioritize funding for projects that increase storage, diversify supplies, promote water reuse, and/or establish interconnections<br>• Support water supply regionalization<br>• Require development of drought management plans for public water systems.<br>• Provide technical assistance for irrigation efficiency improvements<br>• Enact policy to increase or protect minimum instream flows<br>• Develop and implement fire safety programs | **Impact assessment** actions are performed to identify and quantify impacts during a drought. The assessment of impacts helps identify and prioritize response options and allocate resources. Impact assessments also produce data that can be used to develop and implement effective mitigation programs prior to the next drought.<br><br>**Examples that may be initiated at the state level include:**<br>• Develop agency-specific protocols for data gathering and reporting in impacted areas<br>• Study the effectiveness of predrought mitigation efforts in reducing impacts<br>• Support and advertise reporting tools, such as the DIR and CMOR<br>• Evaluate reduction in tax revenues from reduced commerce and the resulting impacts to state government due to drought<br>• Study impacts to water quality resulting from wildfires, reduced stream flow, and lower lake levels<br>• Assess impacts to private water supplies | **Response programs** are initiated during or after a drought to reduce or eliminate impacts as they occur and/or respond to an emergency situation because of lack of water.<br><br>**Examples that may be initiated at the state level include:**<br>• Provide emergency funding to establish interconnections for at-risk public water suppliers<br>• Enact policy recommending voluntary water restrictions or requiring mandatory restrictions for nonessential water use<br>• Provide technical assistance for industrial water use/process modifications<br>• Provide grants for improving leak control efforts and water metering<br>• Provide technical assistance to identify alternative water supplies<br>• Support and coordinate feed distribution for livestock owners<br>• Change tax codes to defer income tax on livestock sales<br>• Provide drought forecasting to improve agricultural decision-making<br>• Modify hunting seasons and fishing regulations |

It is also useful to consider drought mitigation, impact assessment, and response options by sector, as has been done by NDMC and other organizations involved in drought planning. In Missouri, the following seven sectors have been impacted by past droughts and will be used to categorize actions and strategies. It is recognized that some actions and strategies apply to multiple sectors.

1. Public Water Supplies
2. Agricultural (farming and livestock production)
3. Industry and Energy
4. Recreation and Tourism
5. Society and Public Health
6. Fish and Wildlife
7. Wildfire Protection/Forestry/Public Lands

Drought mitigation, assessment, and response actions can be further categorized as short-term/immediate or long-term measures. Short-term or immediate actions are those employed to cope with the acute problems caused by drought. These might include water use restrictions in urban areas or hauling water in rural areas. Long-term responses are those used, for example, after a drought to mitigate the impacts of a subsequent drought.

Drought mitigation, assessment, and response actions must support the state's mitigation goals. These goals are introduced in Section 6. Alignment with one or more mitigation goals provides yet another way that drought management options can be categorized.

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# Section 3 Current Use and Resiliency Assessment

## 3.1 Introduction

Resilience—the ability to respond to and recover from a disruption—is becoming more important as the frequency and severity of both storms and droughts increase. Water users can build resilience to drought by adding supplemental sources of water supply, developing drought response plans, and taking other measures. While Missouri is generally characterized by having an abundant supply of both groundwater and surface water, there are distinct regional differences that play a role in determining a water user's resilience to drought. For example, much of the groundwater originating from bedrock aquifers in northern and west central Missouri is highly mineralized and unsuitable for most uses without treatment. In these areas, municipalities and other major water users primarily rely on surface water from reservoirs, streams and their alluvial aquifers, and groundwater from shallow unconfined aquifers where glacial deposits occur. Their ability to tap additional sources of supply is limited, and the impacts of drought may be more severe when their primary or sole source is stressed. In southwestern Missouri, localized groundwater declines have led to supply disruptions during drought periods, forcing some municipalities to secure surface water sources to meet water demands. For more information regarding the physical setting of the state and how it effects water availability, see Sections 2 and 4 of the Missouri Water Resources Plan (Missouri Department of Natural Resources [MoDNR] 2020).

This section quantifies current water use in Missouri and characterizes water sources and source constraints. Regional drought resilience is assessed based on factors such as the type of water source, interconnections, regional and local drought planning, and social vulnerability. This analysis is completed at the regional level, using the nine crop reporting districts discussed in Section 2.2.1 of this report.

### Overview of Section 3 Current Use and Resiliency Assessment

This section discusses current water use, including sources of supply and regional source constraints. It also identifies factors that improve drought resilience and assesses the use of these factors on the regional scale. Subsections are organized as follows:

- Section 3.2 Current Water Use – quantifies current water use on a regional scale using data compiled for and summarized in the 2020 Missouri Water Resources Plan, identifies regional differences in the source of water, and discusses source constraints.
- Section 3.3 Resilience to Drought – identifies factors that improve drought resilience, characterizes drought resilience (primarily regionally) through review of water supply studies and other data sources, and incorporates the Social Vulnerability Index (SVI) as a measure of resilience.

## 3.2 Current Water Use

On average, the 6.1 million people and numerous businesses in Missouri consume 3.2 billion gallons of water each day. Of that demand, 78 percent is supplied by groundwater and the remaining 22 percent is supplied by surface water, as shown in **Figure 3-1**. Statewide, agricultural irrigation comprises the largest portion of consumptive water withdrawals at 65 percent, major water systems make up an additional 25 percent, and the remaining sectors represent a combined 10 percent of annual withdrawals. Based on growth in population, employment, and expansion of agricultural irrigation and other business sectors, statewide consumptive demand is forecasted to increase by 18 percent or 583 million gallons per day (MGD) by 2060. Agricultural irrigation and major water systems are projected to remain the largest consumers of water in 2060 (Missouri Department of Natural Resources [MoDNR] 2020).

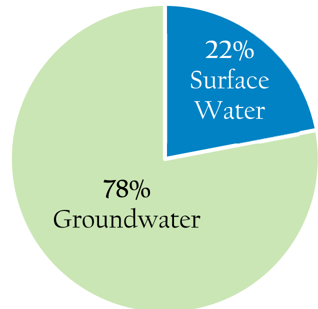


**Figure 3-1. Statewide Water Consumption by Source of Water**

Despite generally abundant water supply in average years to meet these demands, Missouri has been subject to extensive adverse impacts during periods of drought. Additionally, portions of the state may struggle to meet demand even in years with average precipitation and streamflow owing to insufficient supply, inadequate infrastructure, and/or poor water quality, with drought conditions only exacerbating these issues. This section provides an overview of current water use on a regional level, identifying regions where water supply limitations exist because of insufficient quantity and/or poor water quality. Projected increases in population and economic growth (jobs), and their impact on future water demands is also considered.

### 3.2.1 Northwest Region

The Northwest Region lies within the Central Lowlands physiographic province, as shown in **Figure 3-2**. This area was eroded by glacial advances that led to glacial drift aquifers and nearly parallel streams trending north-south toward the Missouri River, the major stream draining this region. Both the glacial drift aquifers and streams are important regional water resources because deep groundwater is high in dissolved minerals from the underlying sedimentary rocks. As shown in **Figure 3-3**, this region lies within a zone of saline groundwater, making it poor quality for drinking water (MoDNR 2002). Additionally, most streams within this region receive minimal groundwater recharge, and during periods of drought, generally decrease significantly in flow (CDM Federal Programs Corporation [CDM Smith] and Barlett & West, Inc. [Barlett & West] 2010). Adequate-quality groundwater for most uses, including irrigation and public water supply, within this region is generally found in the floodplain deposits of the Missouri River and other streams. This alluvial supply is an important water source for this region, providing supply for many cities near the Missouri River (MoDNR 2002a). It is generally not feasible, however, for rural communities without direct access to the alluvial supply to develop the infrastructure to transport this water. In addition to alluvial supply, human-made reservoirs, including Smithville, Cameron, Mozingo, and Grindstone lakes, serve as large drinking water sources in northwest Missouri (CDM Smith and Barlett & West 2010). Approximately 70 percent of the region is supplied by groundwater, including alluvial supply, with the remaining 30 percent served by surface water sources.

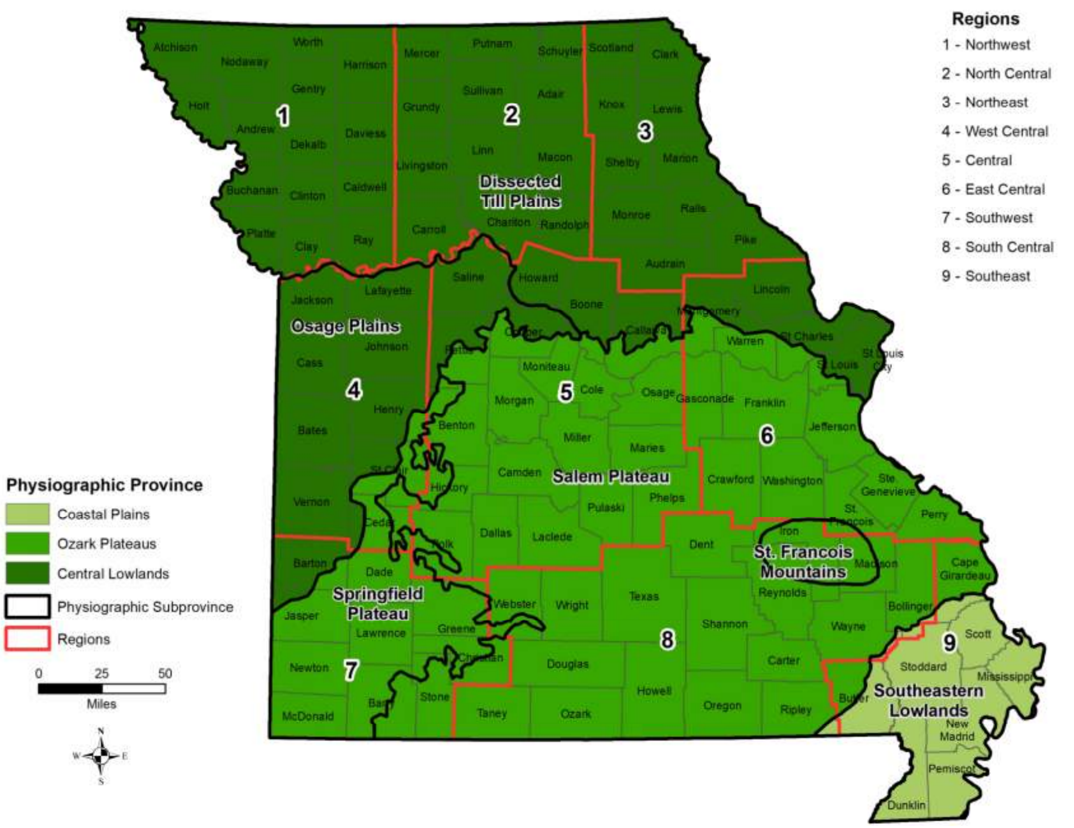


**Figure 3-2. Physiographic Provinces and Subprovinces**


**Figure 3-3. Freshwater-Saline Water Transition Zone**

Domestic and agricultural applications are the primary water uses in this region. Publicly supplied water systems accounted for approximately 50 percent of water use in this region in 2020, similar to most regions of the state. During previous droughts, public water suppliers in several municipalities within this region experienced a supply shortage, some to depletion (CDM Smith and Barlett & West 2010). Agricultural water use for irrigation is the second largest sector, accounting for 30 percent of total water use in the region. Agricultural producers in this region are generally the first to experience impacts from drought. Despite extensive row cropping, irrigation is generally only feasible where alluvial groundwater is adequate. Water use by livestock accounts for approximately 8 percent of total water, demand of which is typically supplied by farm ponds. During prolonged drought periods, farm ponds usually become inadequate (CDM Smith and Barlett & West 2010). During the 2018 drought, livestock producers were the first to feel impacts from the drought as pastures stressed from a dry fall were stunted by the large temperature swing and continued dry weather. The region saw severe impacts for both agricultural producers and public water suppliers. In the city of Cameron, a Stage III water shortage emergency was declared, which included mandatory and voluntary water conservation with an emergency rate structure to incentivize water conservation. Based on significant decline in the city's public supply reservoir, a contract was developed to obtain water from a nearby Missouri Department of Conservation lake through a temporary aboveground transmission line. The city of Hamilton also enacted mandatory conservation measures based on significant decline in reservoir levels in Hamilton Reservoir, a public water supply source for a portion of Caldwell County (MoDNR 2019a).

The majority of the far northern counties in this region are estimated to have a slight to significant decrease in population over the next 40 years. In comparison, Platte and Clay counties in the Kansas City metropolitan area are estimated to experience growth of 85 percent and 63 percent, respectively. Growth rates in the remaining counties in this region range from a decrease of 24 percent to an increase of 15 percent. Overall average population growth of the entire region is estimated to be 43 percent by 2060; however, this average is highly driven by the estimated increase of 250,000 people in Platte and Clay counties. Similarly, regional employment is estimated to increase by approximately 53 percent by 2060, driven primarily by employment growth estimates in the Kansas City metropolitan area.

The northwestern portion of Missouri has the lowest mean precipitation in the state, at 35 to 44 inches annually. The majority of northwest Missouri is characterized as having severe drought vulnerability, with the exception being the areas with alluvial supply, typically located adjacent to the Missouri River (MoDNR 2002b). Challenges with obtaining a reliable source of supply and funding issues associated with a decreasing population and tax base led to the formation of the Great Northwest Wholesale Water Commission. This group includes representatives from water suppliers in 12 counties of the Northwest Region: Andrew, Atchison, Buchanan, Caldwell, Clinton, Daviess, DeKalb, Gentry, Harrison, Holt, Nodaway, and Worth. The commission has assumed the responsibilities of regional planning for future water needs within this 12-county study area (CDM Smith and Barlett & West, Inc 2010). The United States Department of Agriculture (USDA) has invested approximately $32 million toward developing a new regional water system. Planning is ongoing to purchase treated water from Missouri American Water in St. Joseph, and construct 36 miles of water transmission line, booster pump facilities, and elevated water storage tanks to serve portions of Clinton, Dekalb, and Caldwell counties (Cheek 2020). Under another regional water supply project, the National Resources Conservation Service (NRCS) is the lead federal agency assisting the Caldwell County Commission and the Caldwell County Soil and Water Conservation District on the Little Otter Creek Watershed Project in Caldwell County. This project involves constructing a new reservoir, Little Otter Creek Reservoir, designed to provide 1.24 MGD of water to approximately 10,000 people in Caldwell County. The reservoir would also provide flood damage reduction and water recreation opportunities. Groundbreaking for the reservoir took place in March 2021 and the reservoir is currently under construction. Each of these major projects will secure a reliable future source of supply for portions of the Northwest Region.

### 3.2.2 North Central Region

The North Central Region lies within the Central Lowlands, as shown in **Figure 3-2**, and is characterized by parallel streams trending toward the south or southeast. Groundwater flow into these streams (baseflow) is generally low, leading to very low or nonexistent streamflow during drought conditions. Diversions from these surface water sources are not adequate sources of supply. Only the larger rivers within this region, the Missouri River to the south, the Thompson River to the east, and the Chariton River to the west, are reliable sources of surface water for those with access. Long Branch Lake in Macon County is currently the only major lake in the region that provides a water supply source (MoDNR 1998, 2002). This reservoir, managed by the U.S. Army Corps of Engineers (USACE), has 24,400 acre-feet (AF) of water allocated to water supply. Currently, 4,400 AF of that allocation is being used to supply water to the city of Macon and surrounding communities (Nziramasanga 2021). Generally, groundwater resources in this region are poor because of inadequate quantity and marginal quality. Shallow wells in the glacial till yield adequate quality water but are generally low yielding and suitable only for domestic household use. Deeper groundwater with adequate quantity is more mineralized, similar to the Northwest Region. Sulfate, chloride, sodium, iron, and manganese are all constituents that cause poor groundwater quality in the region. Both shallow and deep groundwater wells have historically shown reductions in supply during dry times, with many becoming inadequate during prolonged droughts (MoDNR 2002b). The mean annual precipitation of 36 to 44 inches is low compared to the mid and southern portions of the state.

In 2020, municipal supply accounted for nearly 60 percent of total water use in the region. There are several large-scale confined animal feeding operations in this region, and livestock ranks as the second highest water use, at 28 percent. Eighty percent of water used for animal watering comes from surface water sources. Low streamflow and inflow during dry conditions typically lead to inadequate supply for livestock watering during extended dry and drought periods (MoDNR 2002a). The region also is home to a large thermoelectric plant, Thomas Hill Power Plant, which accounts for approximately 10 percent of consumptive water use for the region. Thomas Hill Reservoir provides the supply source for cooling the plant, in addition to providing flood control.

The population and employment of north central Missouri is estimated to decrease by an average of 5 percent and 3 percent, respectively, by 2060. Individual county growth is estimated to range between a decrease of 20 percent to an increase of 5 percent. Similar to northwestern Missouri, a decreasing population and rate base may lead to funding issues for water system improvements and securing additional sources of supply as funds become more scarce. To address existing regional water supply shortages and develop a reliable water source, the North Central Missouri Regional Water Commission was formed by several local utilities in 2001. Over the past several years, the commission has moved forward in the planning phases of a new reservoir in Sullivan County, the East Locust Creek Reservoir. NRCS is assisting the commission in the process, which could provide 7 MGD of water to the region (NRCS 2021).

### 3.2.3 Northeast Region

Similar to northwest and north central Missouri, the Northeast Region lies within the Central Lowlands, as shown in **Figure 3-2**, and is characterized by parallel streams trending toward the south or southeast. This region is part of the Upper Mississippi River Basin and is drained directly or indirectly primarily by the Upper Mississippi River to the east, with some additional drainage to the Missouri River to the south. Groundwater contribution to streams is generally low, leading to low or nonexistent streamflow during dry and prolonged drought periods. The region contains glacial drift deposits that are underlain by Pennsylvanian and older bedrock; however, the glacial drift deposits are unimportant as an aquifer owing to limited yield, and the Pennsylvanian deposits contain highly mineralized water throughout most of the region. South of the freshwater-saline transition zone, which runs through Audrain and Pike counties, the

Cambrian-Ordovician aquifer is an important source of groundwater (Miller and Vandike 1997). Mean annual precipitation is only slightly higher than that of the Northwest and North Central regions, at 38 to 44 inches.

Many towns rely on surface water supply from an intake in a river or water drawn from a reservoir (MoDNR 1998). Mark Twain Lake in Monroe and Ralls counties is a USACE-managed reservoir with 457,000 AF of conservation storage. Currently, 20,000 AF is allocated from the reservoir for water supply and the remainder is allocated for hydropower (Nziramasanga 2021). It is the only major water supply reservoir in the region. Severe soil erosion from cultivated lands and sediment deposition is a major water quality concern in regional surface water bodies (MoDNR 1998).

The Northeast Region is primarily rural and is characterized by gently rolling hills and fairly extensive plains conducive to growing crops. As such, row crop irrigation is the largest water use in the region, at 43 percent of total water use in 2020. Similar to the Northwest Region, agricultural producers are generally the first to experience impacts from drought. Approximately two-thirds of all irrigation water in this region is from shallow alluvial wells with suitable quality or from groundwater wells south of the freshwater-saline water transition zone. The second largest regional water use is public water systems, at nearly 30 percent. Livestock accounts for the third largest water using sector, with 17 percent of total regional water use.

Similar to the North Central Region, the Northeast Region is estimated to experience a decreasing population over the next 40 years. Overall, the region is estimated to decrease in population by 5 percent by 2060. However, employment is estimated to increase by 20 percent during the same time period, likely due to workers coming in from out of state or from other regions of Missouri.

### 3.2.4 West Central Region

The West Central Region includes a variety of water supply sources. Jackson and Lafayette counties in the northern portion of the region lie along the Missouri River, allowing northern residents access to the high-quality water in the Missouri River alluvial aquifer. This northern portion of the region lies in the Central Lowlands glaciated plains. This area is characterized by low permeability of soils, which leads to rapid runoff and minimal groundwater recharge. Additionally, reduced groundwater contribution to streams leads to low or no flows during drought periods. The farthest reach of glacial ice ended along central Jackson and Lafayette counties, leaving the greatest potential for drift-filled preglacial deposits in the northern portions of each county (MoDNR 2020). Pennsylvanian age bedrock is common throughout the region and yields only modest quantities of marginal-quality groundwater. As shown in **Figure 3-3**, the freshwater-saline water transition zone divides Vernon, St. Clair, Henry, and Johnson counties, leaving the area north of the transition zone with low quantities of highly mineralized groundwater that are generally unsuitable for use. Cedar County, along with the portions of Vernon and St. Clair counties south of the transition zone, generally have groundwater that is suitable quality for most uses without extensive treatment (MoDNR 2002c). The West Central Region has slightly higher mean annual precipitation of 38 to 48 inches.

The West Central Region contains portions of Missouri's largest reservoir, Harry S Truman Reservoir, located partially in Henry and St. Clair counties. This USACE-managed reservoir contains nearly 5.2 million AF of usable storage. Of that storage, approximately 4.0 million AF is flood control storage and 1.0 million AF is conservation storage comprised of sediment reserve (824,600 AF), hydropower (105,00 AF), and water supply (1,000 AF). Additionally, the headwater portion of Stockton Lake is in the southern portion of Cedar County. Stockton Lake is managed by USACE and contains approximately 1.5 million AF of storage, of which nearly 775,000 AF is allocated to flood control while nearly 875,000 AF is allocated to conservation storage including hydropower and water supply. The lake holds a current water supply allocation of 50,000

AF, which is contracted to a public utility in the Southwest Region. A reallocation request is currently in process for the reservoir, which is further discussed in Section 3.2.7. Both Stockton and Truman lakes are also used to generate hydropower.

In 2020, public supply water systems were the highest using water sector in the region, with just over 60 percent of total water use. Despite this large percentage, it accounts for only 7 percent of total public supply water use in the state. Water use by livestock is the second largest use regionally, accounting for approximately 16 percent of the total, and crop irrigation is the third largest regional use, accounting for 12 percent of the total.

The West Central Region is estimated to experience a population increase of 7 percent from 2020 to 2060. Cass County is estimated to see the highest growth rate, at 66 percent, in this timeframe, followed by Cedar County at 20 percent. The remaining counties within the region are estimated to have marginal growth. Employment growth is estimated to follow a similar trend, with a 15 percent regional increase by 2060. Cass and Cedar counties are estimated to experience a 63 percent and 30 percent growth in employment, respectively.

### 3.2.5 Central Region

The northern portion of the Central Region marks the southern extent of glaciation in Missouri. As shown in **Figure 3-2**, the northern portions of Saline, Howard, Boone, and Callaway counties lie within the glacial plains, characterized by parallel streams running toward the Missouri River. Both the glacial drift aquifers and streams are important regional water resources in Saline and Howard counties because deeper groundwater is high in dissolved minerals. Most streams within this northern portion of the region receive minimal groundwater contribution, and during periods of drought generally decrease significantly in flow. Aquifers on the east and south side of the freshwater-saline water transition zone contain usable water of higher quality. The Missouri River also runs through the Central Region, providing high-quality water from the alluvial aquifer to areas along the river. A portion of Benton County lies within the Springfield Plateau, where groundwater resources are generally good but with some local instances of contamination (MoDNR 2002c). The remainder of the region lies within the Salem Plateau. Bedrock within this region is typically permeable, allowing for high rates of recharge. The area is underlain by the unconfined Ozark Aquifer, generally yielding large quantities of suitable-quality water. Many of the streams in this area receive groundwater from springs, so that even during periods of drought, the streams remain flowing at static levels. As shown in **Figure 3-4**, there are four large reservoirs within or partially within this region: Lake of the Ozarks in Camden, Benton, and Morgan counties, Pomme de Terre Lake in Hickory and Polk counties, Stockton Lake in Polk County, and Harry S Truman Reservoir in Benton and Hickory counties. Pomme de Terre Lake is a 644,000 AF reservoir managed by the USACE Kansas City District and is not currently allocated for water supply. Lake of the Ozarks is used to generate hydropower for Ameren Missouri and is not currently used as a water supply source (MoDNR 2002c). In central Missouri, mean precipitation is 38 to 48 inches, a slight but significant increase from the northern regions of the state.

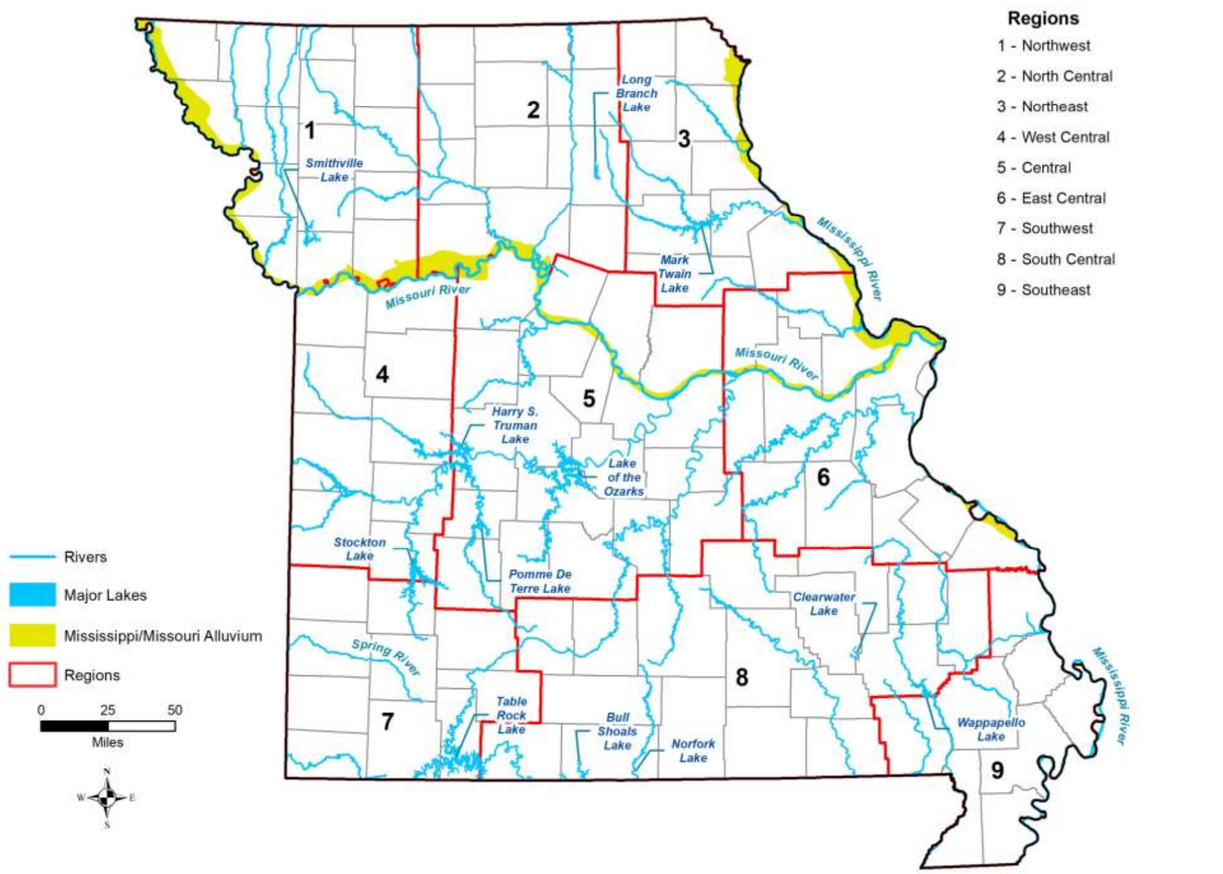


**Figure 3-4. Major Lakes and Rivers**
*Source: U.S. Geological Survey*

In 2020, public water systems were the highest water use sector in this region, accounting for 64 percent of regional water use and 16 percent of total public water system demands statewide. The second largest water use is for livestock, at 13 percent. Several thermopower facilities constitute the third largest water use category, thermoelectric, at 9 percent of regional water use.

The Central Region is estimated to experience 28 percent population growth by 2060. Much of this growth is expected to take place in Boone County, where the city of Columbia and the University of Missouri is located. Columbia is near the Missouri River and primarily uses groundwater from the alluvial aquifer. Boone County is estimated to experience population growth of approximately 66 percent by 2060. Camden County, where a portion of Lake of the Ozarks is located, is also expected to experience substantial growth. Camden County has experienced significant historical population growth, thought to be driven by retirees moving to the area (MoDNR 2020). The county is estimated to grow by nearly 50 percent by 2060. Regional employment is also estimated to grow by approximately 36 percent by 2060.

### 3.2.6 East Central Region

Similar to the Central Region, the East Central Region is split, with glaciated plains in the northern counties and the Salem Plateau in the southern portion of the region, as shown in **Figure 3-2**. As shown in **Figure 3-3**, the freshwater-saline water transition zone comes from the Northeast Region, extending along the eastern border of Lincoln County, then turning south through St. Charles, St. Louis, and Jefferson counties. As a result, the areas north of the transition zone have highly mineralized water that requires extensive treatment to make it potable. Portions of this area adjacent to the Missouri and Mississippi rivers, shown in

**Figure 3-4**, rely instead on the alluvial aquifer, capable of producing large quantities of suitable-quality groundwater. The portion of the region south of the transition zone within the glaciated plains is underlain by the Cambrian-Ordovician aquifer, capable of producing significant quantities of groundwater. It is, however, a shallow aquifer that can be adversely impacted by drought conditions. The remainder of the region is part of the Salem Plateau, underlain by the unconfined Ozark Aquifer. The aquifer receives recharge primarily from precipitation and lateral movement of groundwater through bedrock, and is capable of producing large quantities of suitable-quality groundwater (MoDNR 2002d). As in all regions of central Missouri, mean precipitation is 38 to 48 inches, a slight but significant increase from the northern regions of the state.

The East Central Region includes the city of St. Louis and the St. Louis metropolitan area. As of 2021, the St. Louis metropolitan area has a population of 2.8 million, ranking it as the twentieth largest metropolitan area in the United States. This area includes significant industry, including aviation, biotechnology, chemicals, electric utilities, food and beverage manufacturing, refining, research, telecommunications, and transportation. As such, nearly 75 percent of water use for the region is from public water systems, accounting for just over 20 percent of public water system demands for the entire state. The second largest use is thermoelectric, with 9 percent of total use.

Overall, the East Central Region is estimated to experience moderate growth of approximately 14 percent by 2060. While the city of St. Louis is expected to decline in population and St. Louis County is expected to have a stable population, the remainder of the metropolitan area is expected to grow significantly. Counties considered outside of the metropolitan region are generally expected to show modest growth through 2060.

### 3.2.7 Southwest Region

As shown in **Figure 3-2**, the Southwest Region contains parts of the Salem Plateau, the Springfield Plateau, and the Osage Plains. Barton County and portions of Dade and Jasper counties lie within the Osage Plains, which is characterized by highly mineralized water in deeper aquifers, and small amounts of marginal-quality water closer to the surface. Therefore, most water districts in this area rely on surface water resources (MoDNR 2003). While the Salem and Springfield Plateau is generally known for abundant groundwater, the underlain Ozark Aquifer has seen a slow and steady decline in groundwater levels in portions of McDonald, Newton, Jasper, Christian, and Greene counties. The most severe, localized declines are primarily attributed to self-supplied residential and minor system withdrawals in northern Arkansas, and agricultural (poultry) withdrawals in McDonald County (Miller and Vandike 1997). Mean annual precipitation in this region is significantly higher than the northern and central portion of the state at 42 to 48 inches.

In addition to groundwater sources, this region includes portions of two USACE-managed reservoirs: Stockton Lake in Dade County and Table Rock Lake located partially in Barry and Stone counties, as shown in **Figure 3-4**. Total reservoir storage in Table Rock Lake is 4 million AF. Of that storage, 2.8 million AF is allocated to flood control storage and 1.2 million AF is allocated to conservation storage. The conservation storage at Table Rock is exclusively allocated to hydropower. There is currently no water supply allocation in the reservoir (Nziramasanga 2021). Additional surface water within the region includes the White River System, Shoal Creek of the Spring River System, and the James River. Shoal Creek, the James River, and local water supply lakes provide water to several local utilities. Additionally, City Utilities of Springfield in Greene County has a 50,000 AF water supply allocation from Stockton Lake. Many of these surface water public supply sources and agreements were secured because of regional groundwater limitations and in response to drought conditions. The 1954 drought of record put significant strain on Southwest Region water suppliers. Though most drought periods are not as extreme as 1954, the substantial increase in demands since this period has added significant pressure on both groundwater and surface water resources. Agreements and projects include Lake Lamar in Barton County, constructed following the historic drought

of record in the mid-1950s, and the Stockton Lake allocation, acquired by City Utilities of Springfield in the mid-1990s to supplement dwindling supplies from groundwater sources and local surface water supply, which included Fellows and McDaniel lakes and the James River (CDM Smith 2014). During the drought of 2012, City Utilities of Springfield relied heavily on their surface water allocation from Stockton Lake to replenish their falling municipal lake levels. Similarly, the city of Joplin's water provider, Missouri American Water, was forced to adjust supplies in 2012 by adding 2 feet of emergency dam to Grand Falls, a low dam that creates the Joplin Water Supply Lake on Shoal Creek (not to be confused with the proposed reservoir off Shoal Creek), to offer an additional 68 million gallons in times of drought. Many communities within the Southwest Region were on the threshold of taking drastic measures in 2012, indicating that future drought periods will create significant strain on the regional water supply. Additionally, extensive surface and subsurface mining prior to 1945 in Newton and Jasper counties has negatively impacted surface and groundwater quality, and still poses a threat today if not properly treated and managed (CDM Smith 2014).

In 2020, the largest water using sector in the Southwest Region was public supply, with 74 percent of total regional water use, accounting for 27 percent of public supply water use statewide. The second largest use is agricultural irrigation at 9 percent. Rapid population and economic growth in the region are expected to increase public supply needs in the future.

The majority of the Southwest Region is expected to experience a significant increase in population over the next 40 years. The region is estimated to experience an average growth of 37 percent by 2060, higher than any other region of the state. Regional average employment is estimated to grow by 44 percent by 2060, also estimated to be higher than any other region in the state. Christian County is estimated to grow by 111 percent, with a 113 percent increase in employment. Greene, Newton, and Stone counties are all estimated to grow significantly by 2060, at 36, 42, and 45 percent, respectively.

In response to groundwater declines and significant supply gaps during drought periods, several regional studies have been completed, aimed at securing an additional source of water supply. Many of these studies have been completed by Southwest Missouri Regional Water, which consists of the Southwest Missouri Joint Municipal Water Utility Commission and the Tri-State Water Resource Coalition. These sister organizations include members from several public water utilities in southwest Missouri and have worked collaboratively with USACE, MoDNR, and others to evaluate current and future supply and demand gaps and to secure future water supply sources. The commission concluded that in drought conditions, the 16-county region could experience a supply gap of 39 MGD by 2070 (CDM Smith 2014). As a result, the commission identified three existing USACE reservoirs—Stockton Lake, Table Rock Lake, and Pomme de Terre Lake—as priority options for additional water supply. A reallocation request for 39 MGD from Stockton Lake is currently under evaluation by USACE. Additional requests may be made at Pomme de Terre and/or Table Rock lakes pending the results of the initial reallocation request at Stockton Lake. Missouri American Water in Joplin is working to build a reservoir to address water supply shortages, especially during drought conditions. According to Missouri American Water, during drought conditions the provider has come within 12 hours of having to enact mandatory water conservation measures because of low flows on their main source of supply, Shoal Creek, and groundwater supplemental supply pumps have been lowered twice by at least 100 feet because of declining water levels in the aquifer. Site selection for the proposed reservoir was completed in 2019 (Missouri American Water 2020). The USACE permitting process is currently underway and field investigations started in spring 2021. Once complete, the new reservoir will hold approximately 8 billion gallons of water (Missouri American Water 2021).

### 3.2.8 South Central Region

The South Central Region lies primarily in the Salem Plateau of the Ozarks, where bedrock is typically overlain with permeable weathered rock, allowing for high rates of groundwater recharge. Water supply wells within this region typically yield large quantities of suitable-quality water. The unconfined Ozark Aquifer in this region receives recharge from precipitation and lateral movement of groundwater. As shown in **Figure 3-2**, the regional exception lies in the St. Francois Mountain area, in portions of Reynolds, Iron, Madison, and Wayne counties. This area is characterized by igneous rock that creates a poor aquifer that supplies low quantities of water (MoDNR 2003). On the eastern edge of the region, Taney County is bordered by the headwaters of Table Rock Lake, shown in **Figure 3-4**. The portion of the White River immediately downstream of Table Rock Dam is Lake Taneycomo. The continuously growing tourist area of Branson, which is adjacent to Lake Taneycomo, placed demands on the groundwater supply that were significant enough to cause the town to seek and secure Lake Taneycomo as the primary public supply water source (CDM Smith 2014). Portions of Bull Shoals Lake and Norfork Lake are in the far southern part of the region, in Ozark County. Both reservoirs have small water supply allocations owned by water utilities in Arkansas, where most of the reservoirs are located (Nziramasanga 2021). Mean annual precipitation in this region is 42 to 48 inches, significantly higher than the northern and central portions of the state.

In 2020, public water systems were the largest water supply users in the region, accounting for 57 percent of regional water use. Agriculture is also prominent, with irrigation accounting for 27 percent of total water use and livestock accounting for 8 percent. The region is estimated to grow modestly by 21 percent by 2060; however, Taney County is estimated to increase in population by approximately 61 percent. Employment estimates are higher, with a 36 percent increase in employment estimated by 2060. Taney County is estimated to experience a 60 percent growth in employment by 2060.

### 3.2.9 Southeast Region

This predominately rural region is noted for large agricultural areas and is commonly referred to as the Bootheel or Southeastern Lowlands. The region is covered by alluvium comprised of sand, gravel, silt, and clay that was deposited by the St. Francis, Black, Mississippi, and Ohio rivers. Bordered by the Mississippi River to the east, the area is very flat, with fertile alluvial soils and a warm, moist climate, making this one of the more productive agricultural regions in Missouri. While the region only makes up about 6 percent of the state, it contains approximately 15 percent of Missouri's usable groundwater (MoDNR 2020). Long-term annual precipitation ranges from 46 to 50 inches, the highest of any region in Missouri.

Ninety-seven percent of total regional water use is for irrigation, 99 percent of which is derived from groundwater sources. Over 93 percent of all water used for irrigation in Missouri is used in the Southeast Region. The region is estimated to experience a marginal population growth of 6 percent by 2060. Dunklin, Pemiscot, New Madrid, and Mississippi counties, all located in the far southeastern corner of the region are estimated to experience a decrease in population during this period. Employment, however, is estimated to increase by approximately 37 percent by 2060.

## 3.3 Resilience to Drought

Drought can have extreme impacts throughout the state, and increasing demands, poor water quality, and inadequate water supply in portions of the state only intensify these impacts. Therefore, drought resilience planning is highly encouraged to help communities meet their drought planning goals. This section provides a regional view of current resilience to drought based on source of supply, infrastructure interconnections, drought planning, and social vulnerability.

### 3.3.1 Supply Source

Both groundwater and surface water sources in certain portions of the state have limitations, including limited quantity and poor quality. Short- and long-term droughts exacerbate these limitations, and often introduce additional obstacles to maintaining adequate water supply. Though approximately fifty percent of Missouri's population receives their drinking water directly from the Missouri River or its associated alluvium, most surface water systems in Missouri use reservoirs for raw water storage (MoDNR 2020, MoDNR 2019b). These reservoirs are intended to maintain sufficient supply to operate without interruption through seasonal wet and dry periods. However, small and medium reservoirs are vulnerable to drought conditions. While some water systems are able to divert surface water from streams, limited runoff and recharge can result in little to no flow and reduced water levels that are no longer able to satisfy system water demands. Larger reservoirs may face similar reductions in water levels during an extended drought. Additionally, reduced water volumes in any surface water source can degrade water quality by causing increased concentrations of total dissolved solids, inorganic compounds, organic materials, nutrients, and sediments. Increased concentrations of these constituents along with elevated water temperatures can promote algal blooms that make water treatment difficult and place additional strain on an already struggling water system. Groundwater systems may also experience drought-induced complications. Shallow localized aquifers are more prone to drought impacts because they rely on surface water infiltration or flow in surface streams to recharge. As water levels in a shallow aquifer drop, levels of total dissolved solids, alkalinity, salinity, organic materials, and inorganic materials can rise quickly. While large, high-volume aquifers are less likely to see these impacts, long-term drought conditions can influence water quality and quantity in these sources as well (MoDNR 2019b).

One method to build resilience to drought, particularly for public water systems, is to secure a combination source of groundwater and surface water supply. Water providers with combination supply sources can supplement supply in cases where either surface water or groundwater becomes limited. **Table 3-1** provides the regional percentages of public water users that have a groundwater, surface water, or combination source. Central portions of Missouri have the highest percentage of public water users with both groundwater and surface water sources. East central and west central Missouri have the highest percentage of public water users with combination sources, with 65 and 64 percent, respectively. All regions in northern Missouri have less than 15 percent of water users with a combination source; the Southeast Region has no public water providers that maintain a combination source.

The ability to secure a combination source of supply is highly dependent on source availability, revenue, and cost-benefit analysis. Areas with adequate single-source supply during drought periods may see little value in securing an additional source of supply. As discussed in Section 3-1, southeast Missouri generally receives higher-than-average precipitation compared to the rest of the state, and has abundant, high-quality groundwater sources. While this region currently has no public users with a combination water source, this does not indicate a higher susceptibility to drought, but instead a lower resiliency to drought, as it pertains to the ability to shift to a different source of supply. On the other hand, public water systems in northern and central Missouri, where single-source supplies are less reliable, may be more susceptible to drought. Systems with a combination water source are considered to have a higher resiliency to droughts, should they occur. Susceptibility is further explained in Section 5.2, Regional Vulnerability in Missouri.

**Table 3-1. Regional Percentages of Public Water Users with a Groundwater, Surface Water, or Combination Source (*Source: Safe Drinking Water Information System [SDWIS] Database*)**

| Region | Percentage of Publicly Supplied Population with Groundwater Source | Percentage of Publicly Supplied Population with Surface Water Source | Percentage of Publicly Supplied Population with Combination Source |
|---|---|---|---|
| **Northwest** | 64 | 22 | 14 |
| **North Central** | 21 | 75 | 4 |
| **Northeast** | 28 | 64 | 8 |
| **West Central** | 27 | 9 | 64 |
| **Central** | 69 | 2 | 29 |
| **East Central** | 15 | 20 | 65 |
| **Southwest** | 46 | 1 | 53 |
| **South Central** | 80 | 13 | 7 |
| **Southeast** | 93 | 7 | 0 |

### 3.3.2 Interconnections

Public water systems with inadequate water supply may construct interconnections with nearby water suppliers that have excess supply. These interconnections allow water systems with excess supply or capacity to fully supply or supplement an existing system in need of water. In Missouri, these interconnections may operate on a permanent, active basis, where water is regularly supplied, or an emergency basis, where water is supplied when the purchasing system reaches a threshold of water need. Both emergency and permanent active interconnections are contingent on feasibility and cost-benefit analyses but are a highly recommended component of drought planning to increase resiliency through securing a supplemental supply source. It may also be beneficial to establish multiple interconnections, as drought impacts are likely to be seen throughout neighboring systems. The ability to establish interconnections is also dependent on topography and proximity to a neighboring system with excess supply. In southern Missouri, interconnections may be less feasible, especially in the Ozark Mountains characterized by rolling hills and shallow bedrock. In these areas, the cost to construct the subsurface infrastructure necessary for an interconnection may not be feasible for most water systems.

**Figure 3-5** provides a map of systems with active and emergency connections throughout the state. West central Missouri has the highest percentage of the publicly supplied population covered by an interconnection. The Kansas City metropolitan area is shown to have a high number of systems with interconnections. Approximately 89 percent of public water customers in the West Central Region are connected to either an active or emergency interconnection. Southwest, southcentral, and southeast Missouri have the lowest percentage of public supply population served, with interconnectivity at 3, 12, and 15 percent, respectively. A summary of population served by interconnections is provided in **Table 3-2**.

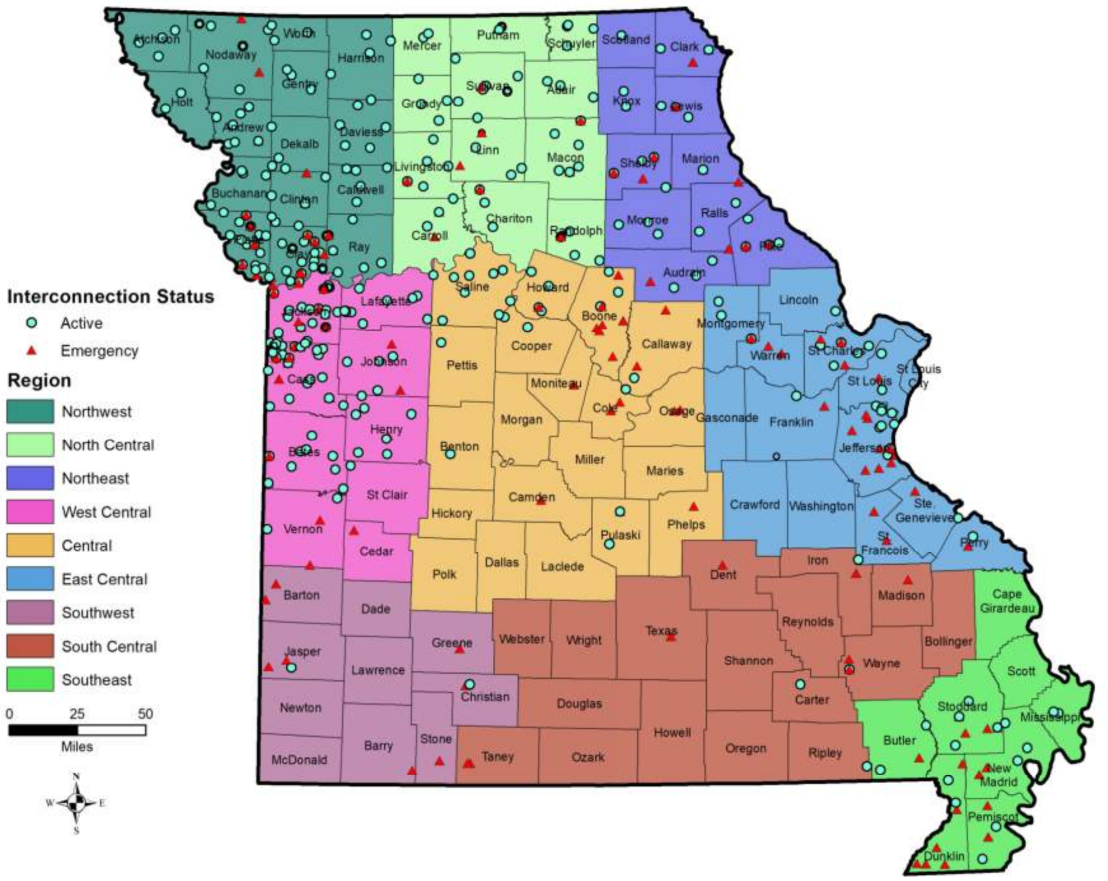


Figure 3-5. Public Water System Interconnections

**Table 3-2. Regional Percentages of Public Water Users with Emergency and Active Interconnections (*Source: SDWIS Database*)**

| Region | Percentage of Publicly Supplied Population with an Emergency Interconnection | Percentage of Publicly Supplied Population with an Active Interconnection | Percentage of Publicly Supplied Population with an Emergency and/or Active Interconnection |
|---|---|---|---|
| **Northwest** | 34 | 37 | 61 |
| **North Central** | 20 | 50 | 53 |
| **Northeast** | 41 | 44 | 61 |
| **West Central** | 77 | 77 | 89 |
| **Central** | 38 | 4 | 42 |
| **East Central** | 55 | 21 | 74 |
| **Southwest** | 2 | 0 | 3 |
| **South Central** | 11 | 1 | 12 |
| **Southeast** | 11 | 5 | 15 |

### 3.3.3 Regional Drought Planning

Building resilience to drought includes planning, preparation, communication, coordination, and operational expertise (MoDNR 2019b). While several major cities in Missouri have a planned response to drought conditions, smaller towns seldom have a dedicated drought response plan. Even major cities in

Missouri with drought planning often have a response that falls under a climate action and adaptation plan or an emergency response plan, as opposed to a dedicated drought response plan. MoDNR encourages the development of local and regional drought response planning teams that can develop drought response plans to identify potential impacts from drought, weaknesses in the system, and goals to minimize impacts (MoDNR 2019b).

While a dedicated drought plan is considered ideal, several regions have sought to build drought resilience through regional projects aimed at establishing additional sources of supply. As discussed in Section 3.1 and shown in **Figure 3-6,** in northwest Missouri planning is in progress for the Great Northwest Wholesale Water Commission Pipeline Project and Little Otter Creek Reservoir Project. In north central Missouri, the East Locust Creek Reservoir Project is currently in the planning phase, and a water utility in southwest Missouri is working toward the Shoal Creek Reservoir Project. The Southwest Missouri Regional Water reallocation project would also serve several water utilities in portions of central, southwest, and south central Missouri. Each of these projects will assist in managing regional drought by securing additional water supply and increasing drought resiliency for communities.

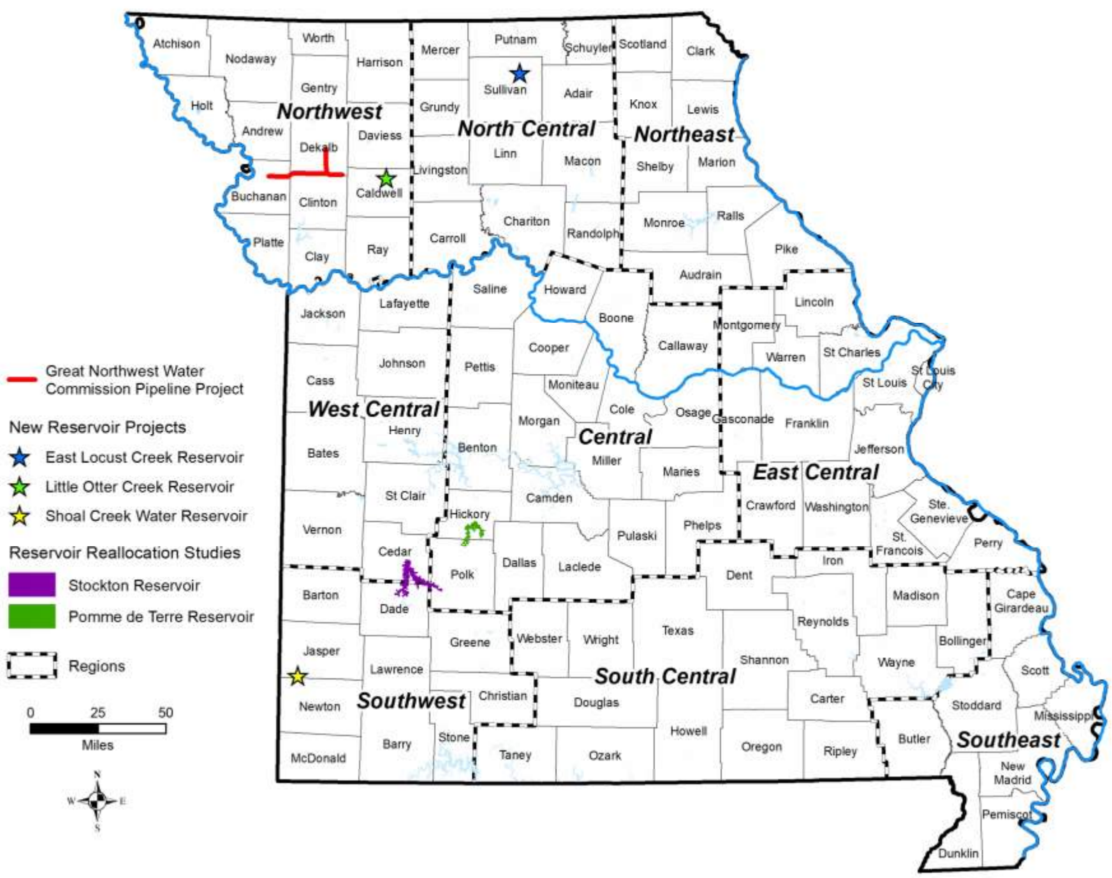


**Figure 3-6. Regional Water Supply Projects**

## 3.3.4 Social Vulnerability Index

SVI is calculated on a county-level basis by the Centers for Disease Control and Prevention (CDC). SVI measures vulnerability to environmental hazards based on personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence. SVI is used by the Missouri Department of Public Safety to help determine where mitigation resources might be used. **Figure 3-7** illustrates 2018 county-level SVI. Scores in the top 20

percent, in dark red, show counties considered the most vulnerable to hazards, while scores in the bottom 20 percent, in light beige, show counties considered the least vulnerable to hazards. SVI scores at the regional level were calculated for this report and are shown in **Table 3-3**. While SVI represents vulnerability and the ability to respond to a wide variety of hazards, it can also help policy makers in determining a region's ability to respond to a drought situation quickly and appropriately.

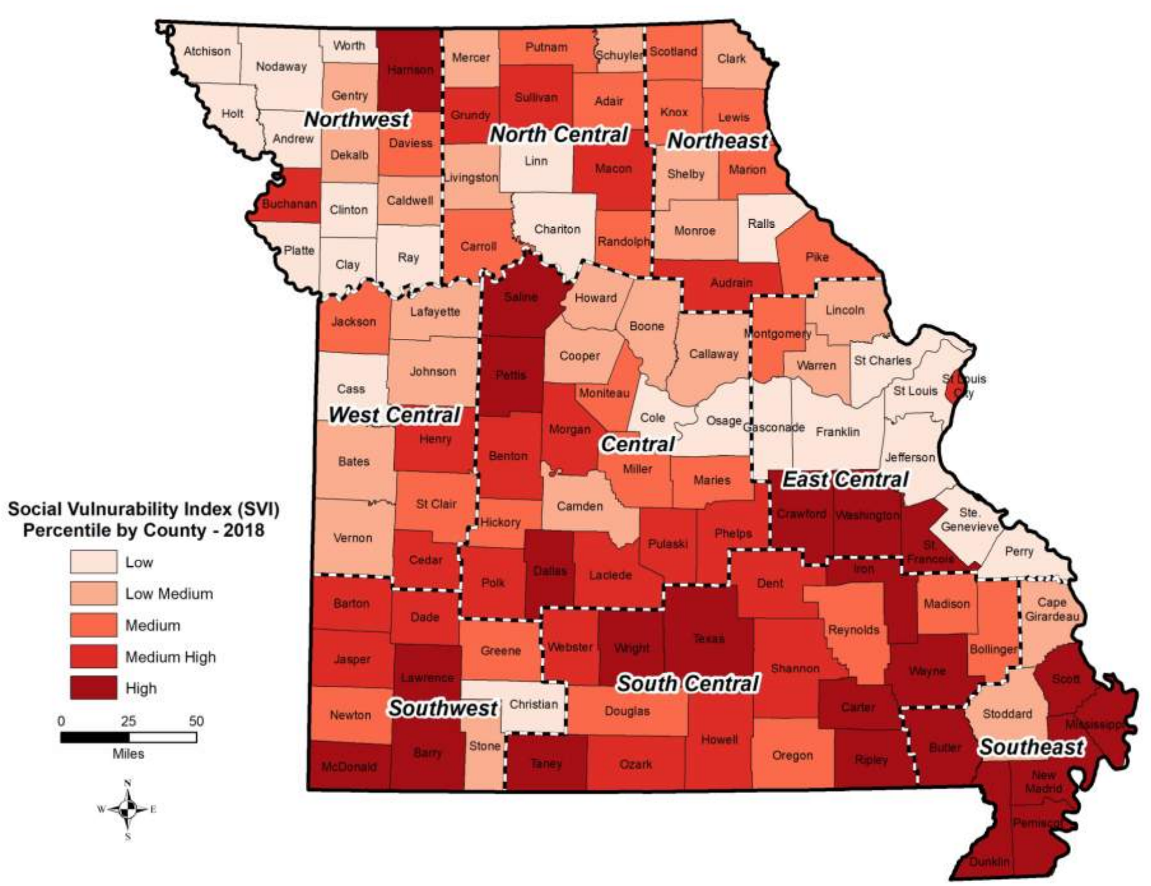


**Figure 3-7. Social Vulnerability Index**
*Source: CDC 2018*

### 3.3.5 Overall Drought Resilience

Drought impacts each region of the state differently based on a number of factors. While water supply availability and current water use is a main factor in determining susceptibility to drought conditions, resilience is based on the ability to prepare for, respond to, and recover from drought. Resilience to drought increases with supplemental sources of supply, either from the ability to use a combination of water sources or from an interconnection with a neighboring water system. Drought planning and water supply projects at a local and regional level also increase drought resiliency.

**Table 3-3** provides an overview of resilience as assessed within this section. Regions are ranked qualitatively based on their relative performance in each of the resiliency categories, with 1 being the most resilient (highest resiliency) and 9 being the least resilient (lowest resiliency). West central and East Central Missouri are considered to have the highest resiliency relative to the other regions. A large portion of the population in these regions is under a combination water source and has an active or emergency interconnection. Additionally, the population is only expected to increase marginally over the next 40 years, indicating that water demands are not likely to increase substantially within the regions. Southeast Missouri is considered to have the lowest resiliency relative to the other regions. Social vulnerability in this

portion of the state is high, likely owing to its rural setting with little infrastructure, low population, and lack of major facilities. There are no water providers in the region with a combination supply source, and only 15 percent of the public supply population is covered by an interconnection. While resiliency is low in the Southeast Region relative to other regions, the region has one of the most abundant and reliable sources of supply and has not shown to be especially susceptible to drought.

**Table 3-3. Regional Drought Resilience**

| Region | Percent Change in Population 2020–2060 | Percentage of Publicly Supplied Population with Combination Water Source | Percentage of Publicly Supplied Population with an Emergency and/or Active Interconnection | Number of Regional Water Supply Projects | Social Vulnerability Index | Overall Regional Resiliency Ranking |
|---|---|---|---|---|---|---|
| **West Central** | 7 | 64 | 89 | 0 | Medium | 1 |
| **East Central** | 14 | 65 | 74 | 0 | Medium Low | 1 |
| **Northwest** | 43 | 14 | 61 | 2 | Medium Low | 2 |
| **Southwest** | 37 | 53 | 3 | 3 | Medium High | 3 |
| **North Central** | -5 | 4 | 53 | 1 | Medium | 4 |
| **Northeast** | -5 | 8 | 61 | 0 | Medium | 5 |
| **Central** | 28 | 29 | 42 | 1 | Medium | 6 |
| **South Central** | 21 | 7 | 12 | 1 | Medium High | 7 |
| **Southeast** | 6 | 0 | 15 | 0 | High | 8 |

For the purpose of this plan, resiliency is primarily characterized for the public water supply water use sector. Resiliency to drought conditions in other water using sectors is also important; however, the data to assess these sectors is not readily available. Drought resiliency practices in agriculture may include performing water audits to reduce water demand and increase irrigation efficiency, planting cover crops to increase carbon content and better retain soil-moisture, and adding, expanding, or dredging farm ponds to increase the source of supply. Conservation is an important element of drought resiliency in several water sectors. Developing resilience to drought in all sectors must include planning, preparation, and maintenance. For communities looking to increase drought resiliency, effective elements and goals of drought planning are discussed in Section 6, Drought Mitigation and Response.

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# Section 4 Assessment of Drought-Related Damages

## 4.1 Introduction

Drought damages can range into the millions and billions of dollars and are among the costliest of weather and climate disasters. According to the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI), between 1980 and 2021, 29 separate droughts have cost the United States at least $267.8 billion (Consumer Price Index-adjusted to 2021 dollars), with an average cost of more than $9.6 billion for each event (NOAA NCEI 2021). Across the United States, the cost associated with impacts from drought since 1980 trails only hurricanes and severe thunderstorms; the cost exceeds that from flooding, freezing, wildfire, and winter storms.

### Overview of Section 4 Assessment of Drought-Related Damages

This section identifies damages from drought events and provides estimates of economic damages from drought to agriculture, municipal water supply, power production, and tourism and recreation. Secondary, indirect effects are also identified. Subsections are organized as follows:

- Section 4.1 Introduction – provides historical examples of reported drought-related damages in Missouri.
- Section 4.2 Agriculture – drought-related agricultural crop loss and livestock forage loss is quantified using historical U.S. Department of Agriculture (USDA) data on payments to farmers for losses. A ranking of regions by the relative potential for agricultural drought impacts is presented.
- Section 4.3 Municipal Water Supply – drought-related damage for municipal water supply is measured by the economic value of having reliable water supply. A ranking of regions by the relative potential for municipal water supply drought impacts is presented.
- Section 4.4 Industrial Water Use – drought impacts in the self-supplied industrial sector are related to the loss of productivity from reduced water availability among industries that are water-dependent. U.S. Geological Survey (USGS) data on water use by industry and mining operations are used to assess the relative potential for industrial sector drought-related impacts by region.
- Section 4.5 Power Production – power generation by region is assessed and the Federal Emergency Management Agency (FEMA) loss of service factor is used to estimate potential economic impacts from a reduction in power generation from drought.
- Section 4.6 Tourism and Recreation – historical information from the Missouri Division of Tourism and the Missouri Department of Natural Resources (MoDNR) Division of State Parks is used to estimate potential economic loss from a reduction in tourism and visits to state parks. A ranking of regions by the relative potential for tourism and recreational drought impacts is presented based on tourism expenditures, tourism sector employment, tourism state sales tax revenue, state park visitors, and state park expenditures.
- Section 4.7 Other Indirect Impacts – a list of potential indirect economic effects from drought is provided.
- Section 4.8 Summary – the potential for drought impacts to each region, relative to other regions, is summarized for the agriculture, municipal water supply, industry, power production, and tourism and recreation sectors combined. Regions are ranked by the relative potential for overall drought impacts.

In Missouri, droughts have had significant economic impact to various sectors of the economy. For example, livestock and poultry losses during and following the 2012 drought in Missouri exceeded $547 million ($593 million in 2020 dollars) considering increased feed costs, changes to livestock sales and inventory, and livestock mortality, according to University of Missouri (MoDNR 2013). As defined in Section 2.3, a drought impact is an observable effect on human activity or a natural process at a specific time that is directly caused by drought. Impacts from drought vary with the intensity and duration of the drought event, and the sector of the economy under evaluation. Multiple data sources are available to assess drought impact on the agricultural economy; however, less data is available to assess drought impact on other sectors of the economy. Data on the direct economic impacts of drought are more readily available than the environmental and social impacts.

Drought damages often have a ripple effect. For example, agricultural crop loss results in a loss of income for farmers and a loss of business for farm suppliers. This in turn may cause further economic and social impacts throughout the community. Food prices may be impacted. Such indirect impacts may not be quantifiable but should be acknowledged in drought planning and response.

Estimates of potential drought damages are developed and presented in this section. In some cases, actual damages are hard to quantify but potential damages can be identified for each region and ranked relative to the other regions of the state. By identifying and comparing the potential for damages within and between regions, effective mitigation and response strategies for each region can be selected. Additional discussion of the methodologies used to estimate drought damages are provided in **Appendix B**. County-level data are also presented in **Appendix B**.

### 4.1.1 Examples of Drought Impacts and Damages in Missouri

The National Drought Mitigation Center's (NDMC) Drought Impact Reporter (DIR) is a useful source for identifying and quantifying drought impacts. The DIR, which began operating in July 2005, compiles reports from media sources, agency reports, and individuals.[1] Drought impacts are classified by relevant category or categories. The eight categories of the DIR are listed in **Table 4-1**, along with the count of drought impacts by category for the years 2011 to 2020. A revised version of the DIR released in 2021 does not include impacts prior to 2011.

The Missouri State Hazard Mitigation Plan reported 460 drought-related impacts in Missouri from the DIR as of December 2016. At that time, DIR data included historical impacts back to 1980. Of the 460 impacts from 1980 through 2016; 240 were classified as agriculture; 121 were classified as water supply and quantity; and 104 were classified as relief, response, and restrictions (Missouri Department of Public Safety 2018). One impact can be associated with multiple categories. Impacts were also classified in each of the remaining categories.

[1] The University of Missouri Extension Service encourages farmers and the public to report drought conditions in their area through a link at https://extension.missouri.edu/programs/drought-resources.

**Table 4-1. DIR Count of Drought Impacts in Missouri, 2011 to 2020**

| Category | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 3 | 18 | - | - | 1 | - | 1 | 10 | 2 | - |
| Fire | - | 1 | - | - | - | - | - | - | - | 1 |
| Relief, Response, and Restrictions | 1 | 11 | - | - | - | - | - | 4 | - | 1 |
| Tourism and Recreation | - | 2 | - | - | - | - | - | - | - | - |
| Business and Industry | - | 2 | - | - | - | - | - | - | - | - |
| Plants and Wildlife | - | 5 | - | - | 1 | - | 1 | 4 | 2 | - |
| Society and Public Health | - | 2 | 1 | - | - | - | - | - | - | - |
| Water Supply and Quality | - | 5 | - | - | - | - | - | 2 | - | - |
| **STATE TOTAL** | **3** | **22** | **1** | **0** | **1** | **0** | **1** | **10** | **2** | **1** |

Hyphens indicate no reported impacts.
*Source: NDMC 2021a*

While the quantitative data from the DIR is highly subjective, the individual reports provide insight into the level of public awareness regarding drought impacts. The following are examples of impact reports from the DIR; most reports relate to agricultural impacts from drought:

- *In 2011, drought reduced the Missouri corn harvest by about 24 million bushels and the soybean crop by roughly 20 million bushels. Drought also lowered the production of forage and pastureland. It was estimated that drought caused a loss of $350 million to the state's grain crops. The hay crop was down 15 to 30 percent in parts of Missouri, leaving what was harvested in high demand by out-of-state buyers since drought decimated the hay crop over a large portion of the southern United States. Dairy farmers were paying up to $300 per ton for hay of adequate quality for dairy cattle. Some cattle ranchers have sold cattle to reduce their herd size to match the amount of stored hay for the winter. Researchers from the University of Missouri estimated that the state needed about 13 feet of snow to compensate for the hot, dry summer and restore soil moisture. (Lebanon Daily Record, December 18, 2011)*

- *In 2012, the average price of dry hay in May was $111 per ton, compared to $88 a ton last year, according to the National Agriculture Statistics Service. The price for a ton was $71 in 2010. The price for a ton of alfalfa was $190 in May, in comparison with $125 a ton last year at this time. (Columbia Missourian, June 12, 2012)*

- *Pasture is pretty well gone. Producers have started full feeding hay. Hay supplies are between a third and half of normal. I look for water to become the limiting factor in the next 3 weeks. Have had lots and lots of calls about nitrate accumulation in corn. I look for more corn to be harvested as silage in my area than for grain. The situation is very serious. (Pat Guinan, Missouri State Climatologist, on behalf of an extension livestock specialist in Gentry County, Missouri, July 24, 2012)*

- *Dove hunters in Missouri were urged to be particularly careful this year because drought has limited the food supplies and water sources for the doves, thereby reducing the amount of land suitable for dove hunting. More hunters than usual may be concentrated in smaller areas, increasing the likelihood of an accident if hunters are not careful. Dove season opens on Saturday, September 1. (Columbia Missourian, August 24, 2012)*

- *The governor of Missouri urged crisis centers in the state to address suicide prevention in farming communities because prolonged drought has increased stress to unbearable levels for some in agriculture. Drought has caused crop and pasture losses, forcing some farmers and ranchers to think about how much loss they can sustain before they must alter their operation dramatically or even get out of the business. About 700 fliers were distributed by crisis workers this month. A suicide prevention counselor at Freeman Hospital in Neosho said that their hotline has been getting 40 to 70 calls per week from farmers under great stress after a very difficult summer of drought. (OzarksFirst.com, September 7, 2012)*

- *The low flow in the Mississippi River during December 2012 and January 2013 brought home just how vulnerable shipping and the regional economy could be to disruption. (St. Louis Post-Dispatch, March 20, 2013)*

- *Nearly 100 dairies closed in Missouri during 2012, due to severe drought conditions, according to Dave Drennan, executive director of the Missouri Dairy Association. (Columbia Missourian, September 9, 2014)*

- *Heat and drought have affected wildlife in Missouri by severely curbing the number of insects. Many insect species require shallow, temporary pools of water as they advance through various life stages, but there were fewer such pools. Birds that eat insects were suffering from the lack of food, too, and were swarming bird feeders in compensation for the dearth of insects. Fewer hummingbirds were seen in the Columbia area. (Columbia Missourian, July 28, 2012)*

- *Pollination missteps were occurring in parts of Missouri, due to the hot, dry weather, meaning that the tassels came out before the silks were present or vice versa, according to University of Missouri grain crop specialist Greg Luce. (Brownfield Ag News, July 12, 2018)*

- *Missouri corn was suffering, scarce hay made feeding cattle challenging, and water supplies were low. Pasture production has not been sufficient to support cattle, and hay growth has been about two-thirds of normal, which will make it difficult to feed cattle through the winter. (KOTV-TV CBS 6 Tulsa, August 19, 2018)*

- *Missouri farmers were warned to test baled cornstalks before feeding them to cattle because the droughty summer may have left them high in nitrates, according to University of Missouri Extension livestock specialist Gene Schmitz. Some stalks contained nearly four times the acceptable level of nitrates. (Warrensburg Daily Star-Journal, October 11, 2018)*

- *Nearly 300 Missouri cattle deaths have been attributed to high nitrate levels in hay and drought-stunted corn. Most instances were seen in southwest and south central Missouri. (Boonville Daily News, March 7, 2019)*

- *Missouri's state fire marshal urged the public to avoid outdoor burning as drought has affected the state in recent weeks. (St. Louis Post-Dispatch, October 13, 2020)*

### 4.1.2 Severity of Drought Conditions and Associated Impacts

Throughout this section, drought damages are associated with defined categories of drought severity. The NDMC's U.S. Drought Monitor (USDM) has assigned drought categories (i.e., D0 – abnormally dry, D1 – moderate drought, D2 – severe drought, D3 – extreme drought, and D4 – exceptional drought) at various spatial resolutions since 2000. Data are available for individual states and counties, drainage basins, climate divisions, and other spatial area types. For assessing damages to crops, the USDM Drought Severity and Coverage Index (DSCI) is also used. The DSCI converts drought levels from the USDM categories to a single numerical value for a given geographic area (e.g., county or crop reporting district). The USDM drought categories and the DSCI are described in detail in Section 2. **Table 4-2** lists past impacts reported in Missouri for each level of drought, as compiled by NDMC.

**Table 4-2. Reported Drought Impacts in Missouri for Each Drought Category**

| Category | Historically Observed Drought Impacts in Missouri |
|---|---|
| **D0** Abnormally Dry | • Pasture and row crop growth is stunted; planting is delayed<br>• Fire threat increases<br>• Canoe rental business declines<br>• Landscaping is stressed; lawns are brown; birds show signs of stress<br>• River levels decline |
| **D1** Moderate Drought | • Topsoil is dry; corn yield is small; pastures are not growing; crops are stressed<br>• Urban watering is extensive<br>• Fire threat greater; burn bans begin<br>• Pond and river levels decline |
| **D2** Severe Drought | • Soil cracks are large and deep; corn and soybeans are cut for silage<br>• Vegetable produce is smaller and yields are decreased<br>• Trees are stressed<br>• Surface water levels are very low; low reservoirs are noticeable<br>• Voluntary city water restrictions are requested |
| **D3** Extreme Drought | • Corn is high in nitrates; major crop loss is reported; hay and water for cattle is limited; hay is expensive; producers are hauling water<br>• Burn bans are common; fires spread easily<br>• Mature tree death is common; fish kills occur<br>• Building foundation damage occurs<br>• Ponds are dried; wells are drying; large lakes and reservoirs are extremely low<br>• Local-level mandatory water restrictions are implemented |
| **D4** Exceptional Drought | • Agriculture loss is widespread<br>• Cattle sales increase; cattle are lighter at auctions; producers are culling; premature birthing is reported<br>• Bird hunting decreases<br>• People are in a state of desperation<br>• Landscape goes dormant<br>• People are digging deeper and more wells, extending pipelines<br>• Lack of hydropower strains the electrical grid, raises power prices, and increases likelihood of blackouts |

*Source: NDMC 2021b*

## 4.2 Agriculture

The agricultural sector is typically the first sector to be impacted by drought conditions. Even abnormally dry (D0) drought conditions can have a significant effect on crop production and pasture conditions and result in substantial economic impacts. Agricultural drought impacts are assessed for both crops and livestock in the following sections using USDA information on insurance and relief payments to farmers. This data may not reflect losses among small family farms without crop insurance.

### 4.2.1 Crop Impacts

In 2019, Missouri was ranked second in the nation in the number of farms (95,200). The average farm size was 291 acres. Missouri was nationally ranked fourth in rice production, sixth in soybean production, and eighth in both corn and cotton production (USDA National Agricultural Statistics Service [NASS] 2019). Thus, crop loss from drought conditions in Missouri can have a significant impact on farmers and local communities.

There are two methods used to estimate crop loss from drought conditions. The first is to estimate what crop production might have been in a particular year had the drought not occurred. The difference between actual crop production under drought conditions and the estimate of crop production under normal conditions is multiplied by 5-year average crop prices to derive the estimated value of lost crops. The second method is to examine USDA crop insurance payments for losses caused by drought conditions. The tables and figures in this section summarize the drought-related damages estimated using these methods.

**Table 4-3** shows the 5-year (2016 to 2020) average production and price for the seven major crops grown in Missouri, as obtained from the USDA NASS. A change in planted acres, harvested acres (or harvest ratio), yield, or price per unit, as shown in the table, would result in a change in the production value of that crop. **Table 4-4** provides the anticipated reduction (loss) of Missouri crop production value in millions of 2020 dollars for loss percentages ranging from 10 to 50 percent. Since the production value of soybeans and corn are individually higher than all other crops combined, potential drought-related losses to those two crops are also the greatest by far.

Another frequent metric used to estimate economic impact of drought crop damage is crop insurance payments resulting from drought conditions. Farmers purchase USDA crop insurance policies through their local insurance agents, who then process applications for indemnity payments when crop loss occurs. The USDA Risk Management Agency (RMA) compiles weekly reports of crop insurance indemnity payments, which are published in a Summary of Business database. Loss from drought is one of many causes of loss for which crop indemnity payments are made. Data in the Summary of Business database include state, county, year, month of loss, acres impacted, amount of indemnity paid, and the cause of loss.

**Table 4-3. 5-Year Average Missouri Crop Production, 2016 to 2020**

| Crop | Acres Planted | Acres Harvested | Harvest Ratio | Production Unit | Yield (Units per Acre) | Price per Unit (2020$) | Production Value (Millions of 2020$) |
|---|---|---|---|---|---|---|---|
| Corn | 3,440,000 | 3,270,000 | 95% | Bushel | 159.80 | $3.59 | $1,873.4 |
| Soybeans | 5,670,000 | 5,610,000 | 99% | Bushel | 47.80 | $9.21 | $2,478.9 |
| Cotton | 317,000 | 308,000 | 97% | Pound | 1,188.60 | $0.68 | $251.5 |
| Rice | 208,800 | 199,600 | 96% | 100 Pounds (CWT) | 72.96 | $11.26 | $162.4 |
| Wheat | 620,000 | 478,000 | 77% | Bushel | 64.40 | $4.78 | $144.8 |
| Hay | | 3,066,000 | | Tons | 2.04 | $97.42 | $614.8 |
| Alfalfa | | 256,000 | | Tons | 2.68 | $155.75 | $106.0 |

Note: Hay and alfalfa do not report acres planted as these are perennial crops.
CWT = hundredweight
*Source: USDA NASS 2021b*

**Table 4-4. Potential Value of Crop Loss by Percent Reduction**

| Crop | Expected Value of Crop Loss (Millions of 2020$) | | | | |
|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% |
| Corn | $187.34 | $374.69 | $562.03 | $749.37 | $936.72 |
| Soybeans | $247.89 | $495.78 | $743.67 | $991.56 | $1,239.44 |
| Cotton | $25.15 | $50.31 | $75.46 | $100.61 | $125.77 |
| Rice | $16.24 | $32.49 | $48.73 | $64.98 | $81.22 |
| Wheat | $14.48 | $28.96 | $43.43 | $57.91 | $72.39 |
| Hay | $61.48 | $122.96 | $184.43 | $245.91 | $307.39 |
| Alfalfa | $10.60 | $21.19 | $31.79 | $42.38 | $52.98 |

Weekly RMA Summary of Business data were obtained for Missouri from January 2000 to December 2020. A total of 23,942 drought-related payments with a total value of $2.236 billion (2020 dollars) were identified. The historical DSCI value was calculated for each crop indemnity payment by year, month, and county. The DSCI value was then converted to the corresponding USDM category.

**Table 4-5** summarizes these indemnity payments by year, in 2020 dollars (USDA RMA 2021). On average, there were 1,140 payments made per year because of drought. The number of payments ranges from 19 in 2009, a year in which there were no counties even partially in abnormally dry (D0) conditions, to 3,418 in 2012, a year with numerous counties in severe drought (D2) conditions. The annual total indemnity payment ranged from $66,157 in 2009 to $1.146 billion in 2012, with a twenty year (2000 to 2020) average of $106 million.

The average annual payment per acre from 2000 through 2020 was $111.43 (2020 dollars). Annually, the average payment per acre ranged from $53.31 in 2000 to $248.23 in 2012. While there is a correlation between the DSCI and the number of indemnity payments, the average payment per acre does not correlate with the DSCI. The average payment per acre is influenced by other factors, such as an increase in crop prices in the late 2000s.

**Table 4-5. Annual Drought-Related Crop Indemnity Payments by Year, 2000 to 2020**

| Year | Number of Payments | Average DSCI[1] | Average USDM Drought Condition[2] | Total Payments | Average Payment per Acre |
|---|---|---|---|---|---|
| 2000 | 1,453 | 116 | D1 | $20,368,379 | $53.31 |
| 2001 | 742 | 58 | D0 | $7,083,548 | $62.42 |
| 2002 | 2,377 | 67 | D0 | $84,699,184 | $74.02 |
| 2003 | 2,492 | 173 | D1 | $127,716,144 | $84.75 |
| 2004 | 134 | 17 | D0 | $735,357 | $63.95 |
| 2005 | 2,071 | 139 | D1 | $79,132,838 | $72.15 |
| 2006 | 1,583 | 189 | D1 | $23,825,084 | $66.05 |
| 2007 | 1,327 | 79 | D0 | $31,070,559 | $96.26 |
| 2008 | 352 | 5 | D0 | $12,078,531 | $146.14 |
| 2009 | 19 | 0 | D0 | $66,157 | $89.65 |
| 2010 | 342 | 75 | D0 | $6,732,041 | $130.40 |
| 2011 | 1,618 | 69 | D0 | $187,697,153 | $175.93 |
| 2012 | 3,418 | 253 | D2 | $1,146,208,119 | $248.23 |
| 2013 | 1,661 | 98 | D0 | $249,805,166 | $167.78 |
| 2014 | 378 | 74 | D0 | $6,466,062 | $124.74 |
| 2015 | 188 | 18 | D0 | $3,500,537 | $102.47 |
| 2016 | 344 | 41 | D0 | $3,400,579 | $97.95 |
| 2017 | 704 | 57 | D0 | $21,432,118 | $133.98 |
| 2018 | 1,959 | 160 | D1 | $195,500,008 | $129.93 |
| 2019 | 92 | 7 | D0 | $1,058,335 | $104.15 |
| 2020 | 688 | 44 | D0 | $27,635,794 | $115.82 |
| **Annual Average** | **1,140** | **83** | **D0** | **$106,486,271** | **$111.43** |

[1]DSCI values are only those associated with payments.

[2]The average USDM drought condition for each year is shown for areas associated with payments. A DSCI of 0 to 99 equates to D0, 100 to 199 equates to D1, and 200 to 299 equates to D2. At certain times during each year, counties may have been in a more severe drought condition than the average USDM drought condition listed.

*Source: USDA RMA 2021*

These same drought-related crop indemnity payments from 2000 to 2020 are shown in **Tables 4-6** through **4-9**, organized by region (crop reporting district) and level of drought severity using the USDM categories. The annualized numbers of payments shown in **Table 4-6** are the total numbers of payments from 2000 to 2020 for the given division and drought category divided by the number of years in the period analyzed. The annualized values in **Tables 4-7** and **4-8** are calculated in the same manner. Similar data by county is provided in **Appendix B**.

More than half of the total number of payments, total value of payments, and number of affected acres occur in the Northeast, Northwest, and North Central regions, followed by the West Central and Central regions. The South Central, Southwest, Northwest, and North Central regions have above-average payments per acre. A significant number of payments and number of affected acres are associated with no drought condition (Not Dry), suggesting some disconnect between the insurance agent's definition of drought and the USDM drought condition category for the county. The high number of payments and affected acres associated with D0 reinforces that agriculture can be impacted by even the slightest drought conditions, or that farms may be affected by localized conditions that differ in severity from the county average condition. The payment per acre in crop damages generally increases with the severity of the drought conditions.

**Table 4-6. Annualized Number of Payments by Region, 2000 to 2020**

| Region | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Central | 36 | 40 | 43 | 22 | 16 | 5 | 161 |
| East Central | 29 | 30 | 27 | 15 | 7 | 3 | 111 |
| North Central | 29 | 36 | 44 | 27 | 25 | 4 | 164 |
| Northeast | 45 | 42 | 43 | 27 | 15 | 4 | 176 |
| Northwest | 40 | 42 | 57 | 38 | 35 | 6 | 218 |
| South Central | 5 | 6 | 4 | 1 | 2 | 1 | 18 |
| Southeast | 25 | 30 | 18 | 13 | 6 | 6 | 98 |
| Southwest | 24 | 27 | 22 | 16 | 4 | 3 | 95 |
| West Central | 38 | 44 | 36 | 23 | 12 | 3 | 156 |
| **STATE TOTAL** | **270** | **297** | **293** | **181** | **122** | **35** | **1,197** |

Totals may not add up because of rounding.
*Source: USDA RMA 2021*

**Table 4-7. Annualized Payments by Region, 2000 to 2020 (2020 Dollars)**

| Region | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Central | $640,621 | $1,637,591 | $2,265,244 | $733,567 | $5,610,746 | $1,316,899 | **$12,204,668** |
| East Central | $554,455 | $575,022 | $863,860 | $548,907 | $2,080,587 | $463,787 | **$5,086,618** |
| North Central | $1,132,819 | $2,116,256 | $3,053,112 | $2,309,346 | $7,015,674 | $1,227,943 | **$16,855,149** |
| Northeast | $2,430,936 | $3,113,393 | $5,688,924 | $3,385,443 | $11,754,058 | $2,682,314 | **$29,055,067** |
| Northwest | $1,250,566 | $1,805,827 | $5,274,028 | $6,717,819 | $8,116,710 | $1,085,565 | **$24,250,516** |
| South Central | $68,981 | $192,743 | $102,981 | $11,806 | $82,409 | $33,070 | **$491,992** |
| Southeast | $361,668 | $559,200 | $305,813 | $171,034 | $357,650 | $428,604 | **$2,183,968** |
| Southwest | $1,116,454 | $3,222,616 | $1,137,921 | $1,595,094 | $204,620 | $329,280 | **$7,605,984** |
| West Central | $973,844 | $3,600,353 | $2,655,085 | $2,965,030 | $2,622,237 | $1,260,073 | **$14,076,622** |
| **STATE TOTAL** | **$8,530,344** | **$16,823,001** | **$21,346,967** | **$18,438,046** | **$37,844,690** | **$8,827,536** | **$111,810,585** |

Totals may not add up because of rounding.
*Source: USDA RMA 2021*

**Table 4-8. Annualized Number of Acres by Region, 2000 to 2020**

| Region | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Central | 6,964 | 15,464 | 19,503 | 8,774 | 20,345 | 6,510 | **77,560** |
| East Central | 5,821 | 6,357 | 6,956 | 4,701 | 7,284 | 1,995 | **33,114** |
| North Central | 7,887 | 17,210 | 26,125 | 14,827 | 34,662 | 6,084 | **106,796** |
| Northeast | 23,112 | 28,549 | 42,238 | 28,502 | 36,990 | 8,864 | **168,254** |
| Northwest | 9,635 | 16,968 | 41,098 | 40,886 | 50,915 | 4,923 | **164,425** |
| South Central | 502 | 840 | 566 | 96 | 230 | 182 | **2,415** |
| Southeast | 3,394 | 6,810 | 3,909 | 2,405 | 2,439 | 2,084 | **21,041** |
| Southwest | 6,902 | 13,796 | 8,212 | 9,259 | 1,424 | 1,577 | **41,171** |
| West Central | 11,566 | 27,549 | 23,593 | 17,519 | 12,514 | 7,123 | **99,863** |
| **STATE TOTAL** | **75,782** | **133,542** | **172,199** | **126,969** | **166,803** | **39,341** | **714,637** |

Totals may not add up because of rounding.
*Source: USDA RMA 2021*

**Table 4-9. Average Payout per Acre by Region, 2000 to 2020 (2020 Dollars)**

| Region | Not Dry | D0 | D1 | D2 | D3 | D4 | Average* |
|---|---|---|---|---|---|---|---|
| Central | $101.96 | $113.57 | $115.60 | $87.07 | $201.87 | $251.54 | **$121.04** |
| East Central | $108.01 | $98.04 | $108.73 | $123.55 | $274.04 | $221.45 | **$121.73** |
| North Central | $125.51 | $107.68 | $103.38 | $140.24 | $174.33 | $278.38 | **$129.38** |
| Northeast | $108.78 | $98.82 | $115.41 | $132.34 | $182.42 | $303.73 | **$122.36** |
| Northwest | $126.77 | $102.95 | $120.91 | $129.74 | $141.60 | $222.41 | **$126.00** |
| South Central | $147.73 | $150.20 | $163.23 | $126.59 | $274.84 | $211.93 | **$164.37** |
| Southeast | $116.63 | $98.13 | $106.19 | $94.63 | $118.48 | $189.06 | **$110.76** |
| Southwest | $137.60 | $153.99 | $116.74 | $144.50 | $164.32 | $178.61 | **$140.93** |
| West Central | $102.79 | $106.82 | $97.79 | $112.01 | $127.62 | $218.97 | **$108.49** |
| **STATE AVERAGE** | **$115.35** | **$109.47** | **$112.09** | **$122.62** | **$169.03** | **$232.29** | **$123.10** |

*The average is weighted according to the number of acres per category.
*Source: USDA RMA 2021*

### 4.2.2 Livestock and Forage Impacts

Decreasing moisture content in pastures for grazing livestock is one of the first signs of drought. Extreme drought conditions can result in toxic levels of nitrates in forage and in drought-damaged crops used for silage and baleage (i.e., large round-bale silage). In addition, grazing livestock may begin to eat noxious weeds and potentially toxic plants. Under drought conditions, farmers may have to purchase hay and feed (increasing costs) or sell livestock to reduce operating costs. However, hay prices may be inflated because of the increase in demand, livestock may be underweight because of the drought, and livestock prices may be depressed by the increased supply for sale.

The forage-livestock industry in Missouri uses 11 million acres of private lands for grazing, hay production, and conservation. These enterprises contribute more than $12 billion annually to Missouri's economy and provide income for more than 200,000 people. Missouri is the second-largest producer of grass hay in the country. Missouri's cow-calf herd is the third largest in the country, with more than 4 million cows and calves. Missouri has the second-largest number of beef producers, and the seventh-largest number of dairy farms (University of Missouri 2021).

While the exact economic impact on Missouri from the 2012 drought is difficult to ascertain because of the broad nature of drought impacts, estimated losses to livestock and poultry operations exceeded $547 million when accounting for increased feed costs, changes to livestock sales and inventory, and livestock mortality in 2012 and 2013, according to University of Missouri (MoDNR 2013). Many farmers were forced to sell livestock to reduce operating costs; however, most livestock were underweight because of the drought and prices were lower due to the increased supply for sale. Nearly 100 dairy operations closed during 2012 according to the Executive Director for the Missouri Dairy Association (NDMC 2012).

To more closely assess drought impacts to livestock, the inventory of cattle by county from 2000 to 2021 was obtained from the USDA NASS Missouri Field Office (USDA NASS 2021a). The inventory reported is counted as of January 1st of each year. The statewide total cattle inventory for this period is shown in **Figure 4-1**. On January 1, 2013, the cattle inventory was 250,000 head less than on January 1, 2012. This drop in inventory is indicative of the sell-off that occurred during the drought of 2012. Similarly, a decrease in statewide cattle inventory followed droughts in 2003 and 2018. The market conditions that existed during the Great Recession (2007 to 2009) are likely responsible for the decline in inventory from 2007 to 2011.

**Figure 4-2** shows that the decrease in cattle inventory from January 1, 2012, to January 1, 2013, was not statewide but varied by county. This change in inventory is indicative of the impact of the drought of 2012. Sixty-one percent of counties had a decrease in cattle inventory while the remainder had an increase during 2012. Each region had a mix of counties with both decreases and increases in cattle inventory. **Table 4-10** summarizes the number of counties with a decrease in 2012 cattle inventory by region, along with the percentage of counties with decreases, net change in inventory, and estimated net worth of the inventory change. The Northwest Region had the highest percentage of counties with inventory decreases and the most inventory loss, at 127,000 head. The East Central Region had the lowest percentage (46 percent) of counties with inventory decreases, and the Northeast Region had a slight net gain in cattle inventory. This variation across regions may be owing to the availability of water for livestock or the monthly variation of drought conditions across regions with respect to hay and forage production. The change in 2012 cattle inventory by county is provided in **Appendix B**.

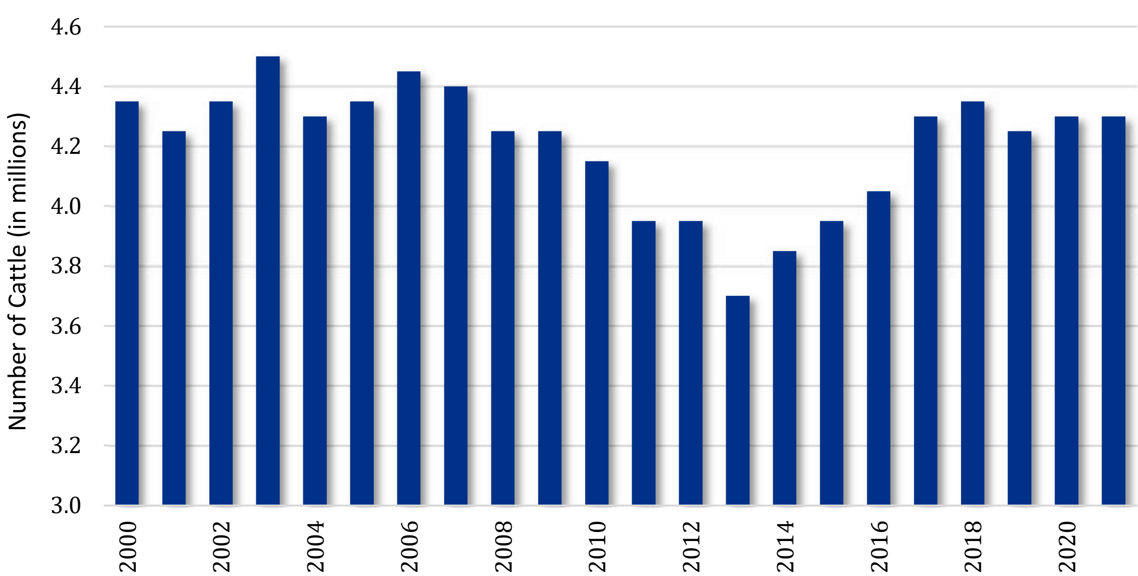


**Figure 4-1. Missouri Cattle Inventory by Year, 2000 to 2021**
*Source: USDA NASS Missouri State Office*

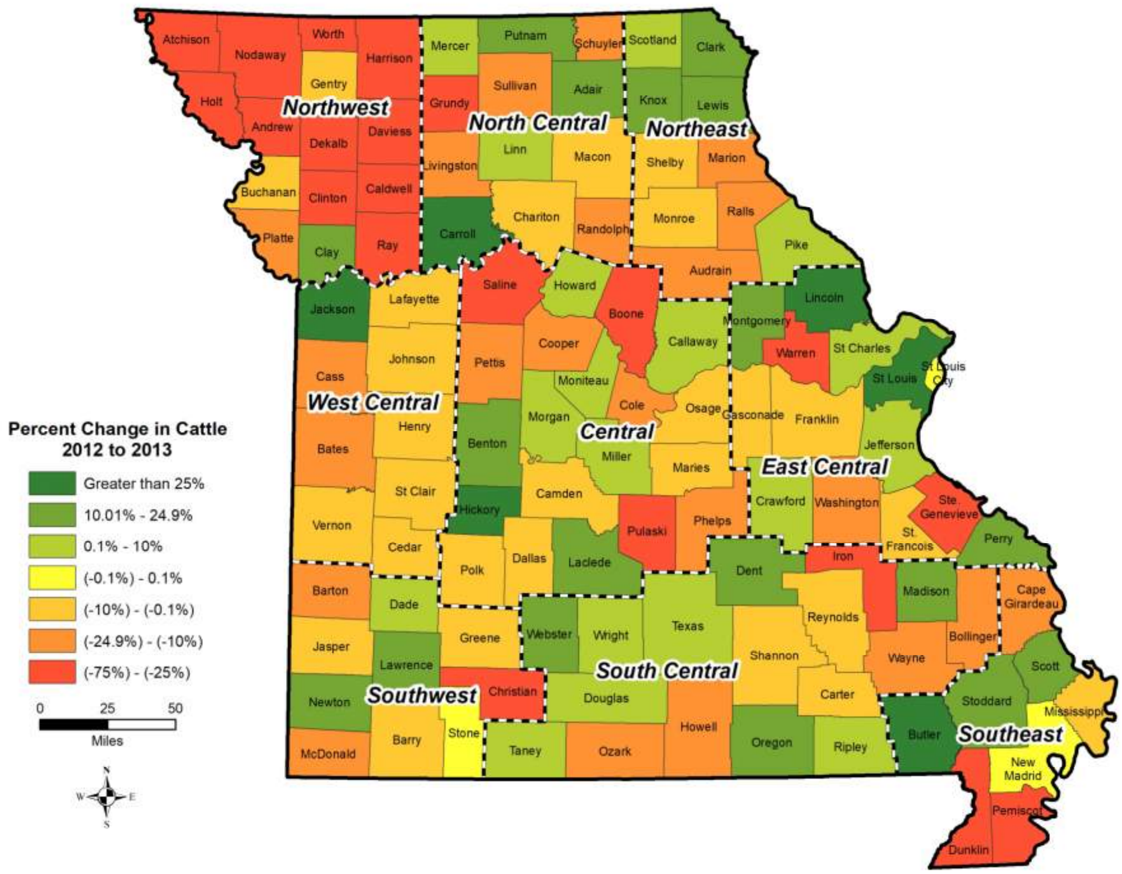


**Figure 4-2. Percent Change in 2012 Cattle Inventory by County**

*Source: USDA NASS Missouri State Office*

**Table 4-10. Counties by Region with Decrease in 2012 Cattle Inventory**

| Region | Number of Counties | Number of Counties with Decrease in Inventory | Percentage of Counties with Decrease | Net Change in Inventory | Net Worth of Inventory Change[1] |
|---|---|---|---|---|---|
| Central | 20 | 12 | 60% | -44,700 | -$32,067,780 |
| East Central | 13 | 6 | 46% | -6,000 | -$4,304,400 |
| North Central | 12 | 7 | 58% | -8,200 | -$5,882,680 |
| Northeast | 10 | 5 | 50% | 500 | $358,700 |
| Northwest | 15 | 14 | 93% | -127,000 | -$91,109,800 |
| South Central | 17 | 8 | 47% | -3,400 | -$2,439,160 |
| Southeast | 8 | 4 | 50% | -5,200 | -$3,730,480 |
| Southwest | 10 | 6 | 60% | -19,500 | -$13,989,300 |
| West Central | 9 | 8 | 89% | -36,500 | -$26,185,100 |
| **STATE TOTAL** | **114** | **70** | **61%** | **-250,000** | **-$179,350,000** |

[1]Assumes 500 pounds per head at $143.48 per CWT.

*Source: USDA NASS Missouri State Office 2021*

United States cattle prices from January 2000 to March 2021 in 2020 dollars are shown in **Figure 4-3.** The decrease in Missouri cattle inventory in 2012 of 250,000 head at the 2012 average price of cattle over 500 pounds ($143 per CWT in 2020 dollars and assuming a minimum of 500 pounds per head) suggests a minimum loss of $179.4 million in 2020 dollars in 2012.

The extended drought that hit portions of the Midwest, including Missouri and the Southern Plains, from 2011 to 2013 is one of the causes attributed to the spike in United States cattle prices during 2013 and 2014 (Burdine and Halich 2016). The forced liquidation of cow herds in these regions at a time when they normally would have been increasing, coupled with other factors, fueled a rise in cattle prices once supply became limited but demand remained high. That is, initially as farmers began to sell low-weight cattle there was a drop in price per CWT owing to the increased number of cattle being sold (supply). Then the resulting low supply following the drought caused an increase in price per CWT. As supply caught up to demand, prices returned to historically normal levels.

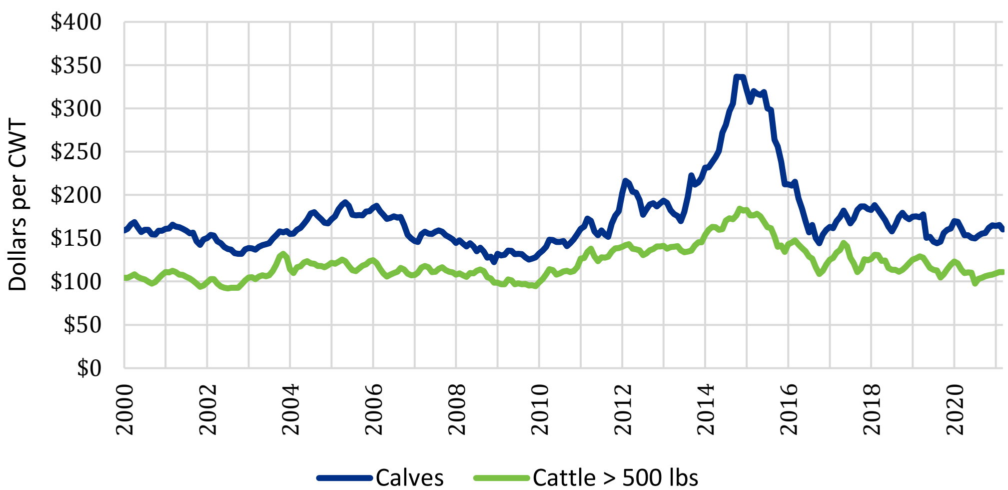


**Figure 4-3. United States Cattle Prices, 2000 to 2021 (2020 Dollars)**
*Source: USDA NASS Missouri State Office*

The monthly price of hay and alfalfa from January 2000 to March 2021 in 2020 dollars is shown in **Figure 4-4**. The price of hay per ton (excluding alfalfa) increased from $85 per ton in July 2012 to $124per ton in October and peaked at $134 per ton (2020 dollars) in June 2013. The price of alfalfa per ton spiked in fall 2011, reaching a peak of $289 per ton (2020 dollars) in December 2011. Alfalfa decreased to $215 per ton in June 2012, increased again in fall 2012, and then reached a peak of $271 per ton in January 2013 and remained high throughout 2013. The price of hay and alfalfa in Missouri can be influenced by market factors in other states. The widespread drought that began in the Southern Plains states in 2010 and worsened during 2011 was one likely cause of the increase in hay and alfalfa prices in Missouri. When drought conditions spread to Missouri and other portions of the Midwest in 2012, prices peaked.

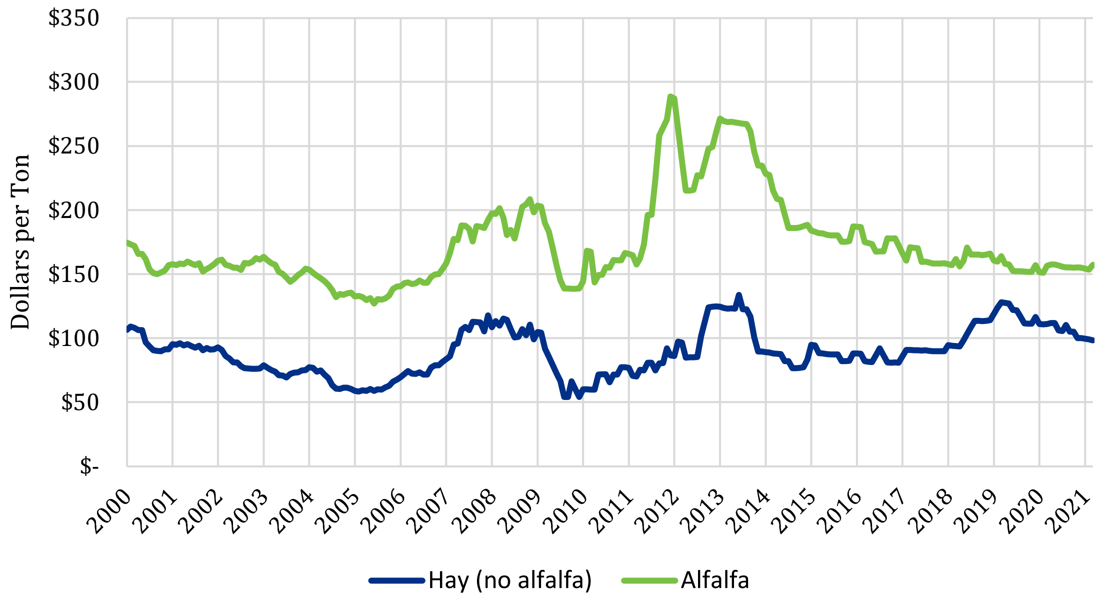


**Figure 4-4. Missouri Hay and Alfalfa Prices, 2000 to 2021 (2020 Dollars)**
*Source: USDA NASS Missouri State Office*

The USDA Farm Service Agency (FSA) provides farmers with relief from drought damages to improved pasture and grazed forage crops through the Livestock Forage Program (LFP). The LFP provides payments to eligible livestock owners and producers of grazed forage crop acreage that suffer loss of grazed forage because of drought. FSA calculates the LFP monthly payment as 60 percent of the smaller of monthly feed cost or the payment rate per head (USDA, FSA. 2020). Table 4-11 shows the 2018 to 2020 monthly livestock payment rates.

A livestock owner is eligible for assistance if their land is in a county that has:

- D2 conditions for at least 8 weeks (eligible for an amount equal to one monthly payment)
- D3 conditions at any time (eligible for an amount equal to three monthly payments)
- D3 conditions for at least 4 weeks, or D4 conditions at any time (eligible for an amount equal to four monthly payments)
- D4 conditions for at least 4 weeks (eligible for an amount equal to five monthly payments)

Annual LFP payments by year and county from 2011 through 2020 were obtained from the USDA FSA Missouri State Office. **Figure 4-5** shows the total annual LFP payments by year for the state. Payments for pasture and forage loss during the 2012 drought were four times those in 2018. Damages from the 2012 drought appear to have extended into 2013. It took farmers longer to reestablish adequate pasture after the extended drought of 2012 than other recent droughts.

**Table 4-11. Example of LFP Payment Rates**

| LIVESTOCK PAYMENT RATES | | | | | |
|---|---|---|---|---|---|
| | | | PAYMENT RATE PER HEAD | | |
| KIND | TYPE | WEIGHT RANGE | 2018 | 2019 | 2020 |
| **Beef** | Adult | Bulls, Cows | $28.07 | $29.34 | $31.89 |
| | Non-Adult | 500 pounds or more | $21.05 | $22.01 | $23.92 |
| | Non-Adult | Less than 500 pounds | | $14.67 | $15.94 |
| **Dairy** | Adult | Bulls, Cows | $72.98 | $76.29 | $82.91 |
| | Non-Adult | 500 pounds or more | $21.05 | $22.01 | $23.92 |
| | Non-Adult | Less than 500 pounds | | $14.67 | $15.94 |
| **Beefalo** | Adult | Bulls, Cows | $28.07 | $29.34 | $31.89 |
| | Non-Adult | 500 pounds or more | $21.05 | $22.01 | $23.92 |
| | Non-Adult | Less than 500 pounds | | $14.67 | $15.94 |
| **Buffalo/Bison** | Adult | Bulls, Cows | $28.07 | $29.34 | $31.89 |
| | Non-Adult | 500 pounds or more | $21.05 | $22.01 | $23.92 |
| | Non-Adult | Less than 500 pounds | | $14.67 | $15.94 |
| **Sheep** | All | | $7.02 | $7.34 | $7.97 |
| **Goats** | All | | $7.02 | $7.34 | $7.97 |
| **Deer** | All | | $7.02 | $7.34 | $7.97 |
| **Equine** | All | | $20.77 | $21.71 | $23.60 |

*Source: USDA FSA 2020*

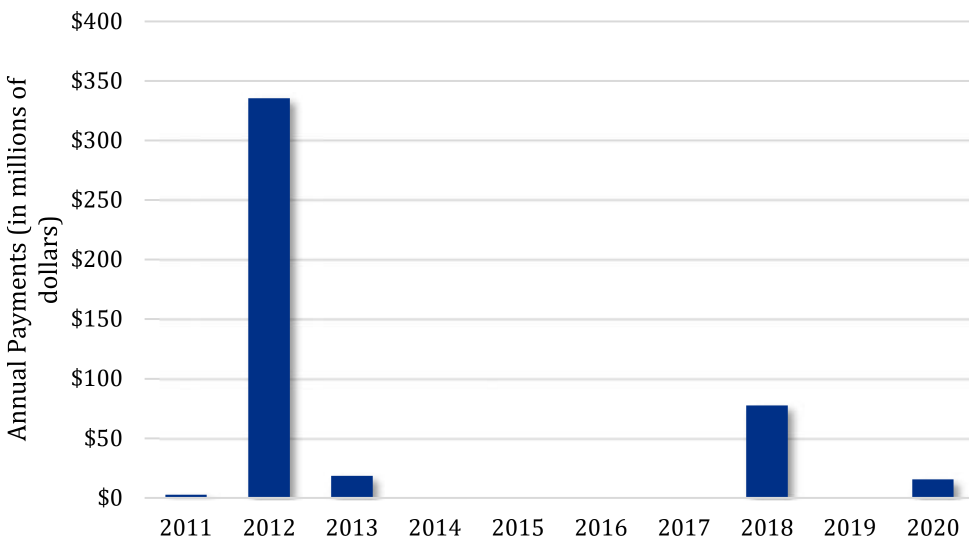


**Figure 4-5. Missouri Annual LFP Payments, 2010 to 2020 (Million 2020 Dollars)**
*Source: USDA FSA 2020*

**Table 4-12** shows the number of counties with LFP payments by year and region. Overall, the Northwest Region had the most counties with LFP payments over the 10-year period, followed by the Central and North Central regions. In 2012, farmers in all counties across the state, except Carter County, received LFP payments.

**Table 4-13** shows total LFP payments in millions of dollars, adjusted to 2020 dollars, by year and region. Of the total $450 million paid out over the 10-year period, 75 percent of payments were in 2012. Overall, one-

fifth of all LFP payments were in the Central Region with $93 million paid over 10 years. The Southwest Region had $81 million paid over the 10-year period. The Southeast Region had the fewest LFP payments with only $5.2 million over 10 years. LFP payments by county are presented in **Appendix B**.

**Table 4-12. Number of Counties with LFP Payments by Year and Region**

| Region | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Central | 0 | 20 | 3 | 0 | 0 | 0 | 0 | 16 | 0 | 2 | **41** |
| East Central | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | **14** |
| North Central | 0 | 12 | 12 | 0 | 0 | 0 | 3 | 12 | 0 | 0 | **39** |
| Northeast | 0 | 10 | 8 | 0 | 0 | 0 | 1 | 9 | 0 | 0 | **28** |
| Northwest | 0 | 15 | 12 | 0 | 0 | 0 | 3 | 15 | 0 | 0 | **45** |
| South Central | 0 | 16 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 7 | **30** |
| Southeast | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **8** |
| Southwest | 3 | 10 | 0 | 2 | 0 | 0 | 0 | 10 | 0 | 10 | **35** |
| West Central | 6 | 9 | 1 | 0 | 0 | 0 | 0 | 9 | 0 | 1 | **26** |
| **STATE TOTAL** | **9** | **113** | **37** | **2** | **0** | **0** | **7** | **78** | **0** | **20** | **266** |

Totals may not add up because of rounding.
*Source: USDA FSA 2021*

**Table 4-13. Total LFP Payments by Year and Region (Million 2020 Dollars)**

| Region | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Central | - | $75.145 | $0.468 | - | - | - | - | $17.340 | - | $0.064 | **$93.017** |
| East Central | - | $17.861 | - | - | - | - | - | $0.017 | - | - | **$17.879** |
| North Central | - | $32.819 | $8.821 | - | - | - | $0.032 | $17.388 | - | - | **$59.059** |
| Northeast | - | $14.144 | $2.228 | - | - | - | $0.009 | $2.766 | - | - | **$19.146** |
| Northwest | - | $30.891 | $6.146 | - | - | - | $0.044 | $16.121 | - | - | **$53.202** |
| South Central | - | $64.644 | $0.923 | - | - | - | - | $4.648 | - | $1.011 | **$71.225** |
| Southeast | - | $5.209 | - | - | - | - | - | - | - | - | **$5.209** |
| Southwest | $0.544 | $52.254 | - | $0.007 | - | - | - | $13.770 | - | $14.458 | **$81.032** |
| West Central | $1.950 | $42.682 | $0.003 | - | - | - | - | $5.661 | - | $0.006 | **$50.301** |
| **STATE TOTAL** | **$2.493** | **$335.649** | **$18.588** | **$0.007** | **-** | **-** | **$0.085** | **$77.711** | **-** | **$15.538** | **$450.071** |

Totals may not add up because of rounding.
*Source: USDA FSA 2021*

As with crop indemnity payments, the total LFP payments by county and year can be organized by crop reporting district and level of drought severity using the USDM categories. Because the LFP data was the annual total for each county by year, the data were matched with the maximum month DSCI for the county and year.

**Table 4-14** shows the number of counties with LFP payments per region from 2011 to 2020 by drought condition. In the South Central Region, there were two counties with LFP payments when the region was in D0 condition. This occurred when the regional drought conditions did not reflect the conditions in the specific county or microclimate in which payments were made. The Northwest Region had the most counties with LFP payments over the 10-year period with 45 payments. Nineteen counties had payments under regional D4 conditions, and 19 counties had payments under regional D3 conditions. The North Central Region had the most counties with payments under D4 conditions with 20 counties over the 10-year period. Nearly half (48 percent) of all counties with LFP payments were under regional D4 drought conditions. The Southeast Region had the fewest counties with LFP payments, all of which were under regional D4 drought conditions.

**Tables 4-15** shows the total LFP payments over the 10-year period by drought condition and region. Across the state, a total of $450 million dollars were paid out over the 10-year period. Of these payments, 78 percent occurred under D4 regional drought conditions.

**Table 4-14. Number of Counties with LFP Payments per Region by Drought Condition, 2011 to 2020**

| Region | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|
| Central | 0 | 5 | 9 | 5 | 22 | 41 |
| East Central | 0 | 0 | 1 | 0 | 13 | 14 |
| North Central | 0 | 0 | 8 | 11 | 20 | 39 |
| Northeast | 0 | 1 | 13 | 3 | 11 | 28 |
| Northwest | 0 | 2 | 5 | 19 | 19 | 45 |
| South Central | 2 | 4 | 5 | 3 | 16 | 30 |
| Southeast | 0 | 0 | 0 | 0 | 8 | 8 |
| Southwest | 0 | 0 | 9 | 16 | 10 | 35 |
| West Central | 0 | 1 | 10 | 6 | 9 | 26 |
| **STATE TOTAL** | **2** | **13** | **60** | **63** | **128** | **266** |

**Table 4-15. Total LFP Payments by Annual Drought Condition and Region (Million 2020 Dollars)**

| Region | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|
| Central | $ - | $ 0.122 | $ 7.411 | $ 6.768 | $ 78.716 | $ 93.017 |
| East Central | $ - | $ - | $ 0.017 | $ - | $ 17.861 | $ 17.879 |
| North Central | $ - | $ - | $ 3.454 | $ 11.367 | $ 44.238 | $ 59.059 |
| Northeast | $ - | $ 0.009 | $ 2.550 | $ 1.809 | $ 14.779 | $ 19.146 |
| Northwest | $ - | $ 0.043 | $ 0.738 | $ 21.896 | $ 30.524 | $ 53.202 |
| South Central | $ 0.009 | $ 0.551 | $ 4.144 | $ 1.877 | $ 64.644 | $ 71.225 |
| Southeast | $ - | $ - | $ - | $ - | $ 5.209 | $ 5.209 |
| Southwest | $ - | $ - | $ 6.931 | $ 21.847 | $ 52.254 | $ 81.032 |
| West Central | $ - | $ 0.034 | $ 2.696 | $ 4.888 | $ 42.682 | $ 50.301 |
| **STATE TOTAL** | **$ 0.009** | **$ 0.759** | **$ 27.942** | **$ 70.453** | **$ 350.908** | **$ 450.071** |

Totals may not add up because of rounding.
*Source: USDA FSA 2021*

### 4.2.3 Potential for Agricultural Impacts from Drought

Counties with more crop acres and livestock inventory have the potential to see more impacts from drought than those with fewer acres and inventory. The 2017 USDA Census of Agriculture indicates that non-irrigated crop acres in Missouri range from 7,700 acres in Carter County to 324,000 acres in Saline County (USDA

2017). **Figure 4-6** shows the relative number of non-irrigated acres by county. Livestock inventory (excluding poultry) ranges from 800 head in Pemiscot County to 2.9 million head in Vernon County. **Figure 4-7** shows the relative inventory of livestock by county. Poultry inventory ranges from none in a few counties to 93 million birds in Barry County. **Figure 4-8** shows the relative poultry inventory by county.

The potential for agricultural impacts from drought in each county and region, relative to the other counties and regions of the state, can be developed by assigning values of 1 to 4 to the quartile rankings of non-irrigated crop acres, livestock inventory and poultry inventory of each county, then averaging the values by region. This relative comparison helps identify which counties and regions could be impacted most by drought solely based on the amount of agricultural activity in each county and region. Comparing this to other factors, such as the likelihood of drought occurring in a region, the susceptibility of the region (e.g., availability of water sources), and the region's resilience to drought (e.g., amount of water storage, existence of drought plans) can help define overall vulnerability. See **Section 6** for an assessment of overall agricultural vulnerability for each region.

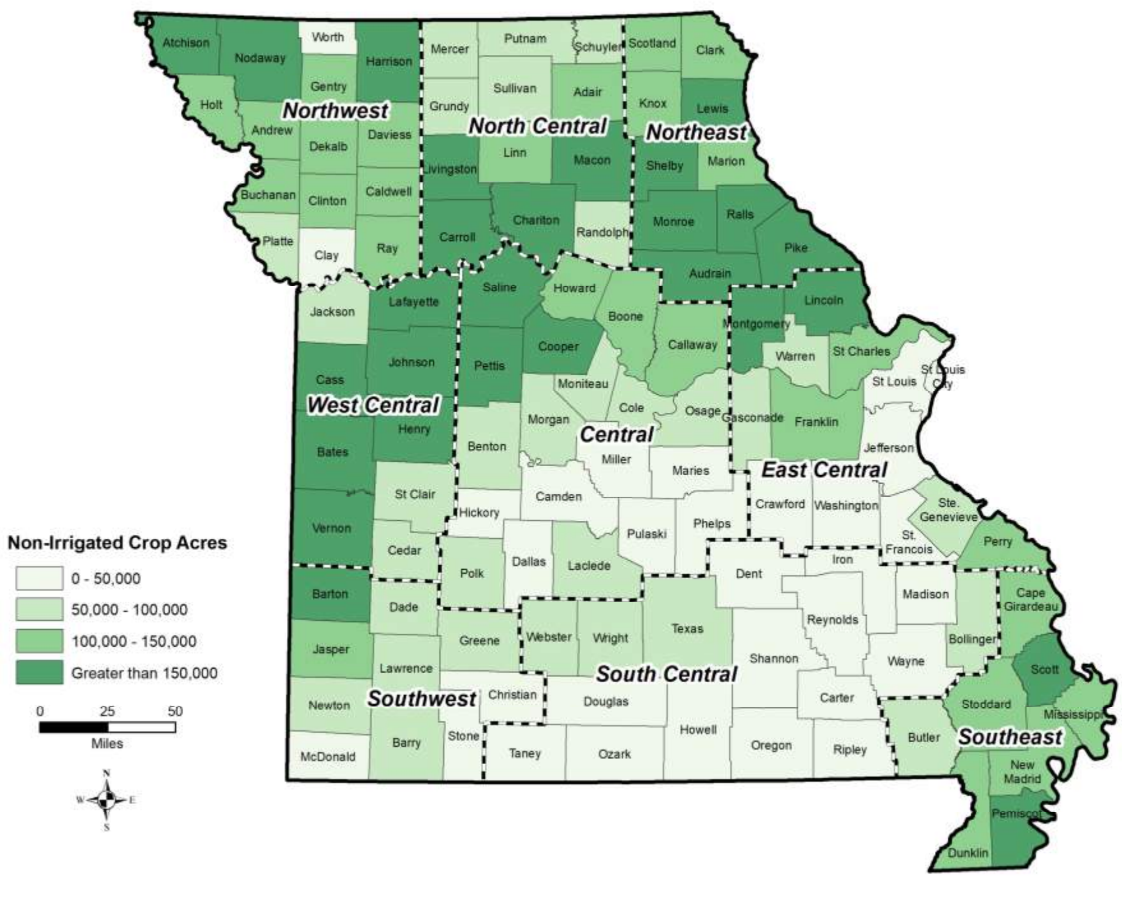


**Figure 4-6. Non-Irrigated Crop Acreage by County**
*Source: 2017 USDA Census of Agriculture*

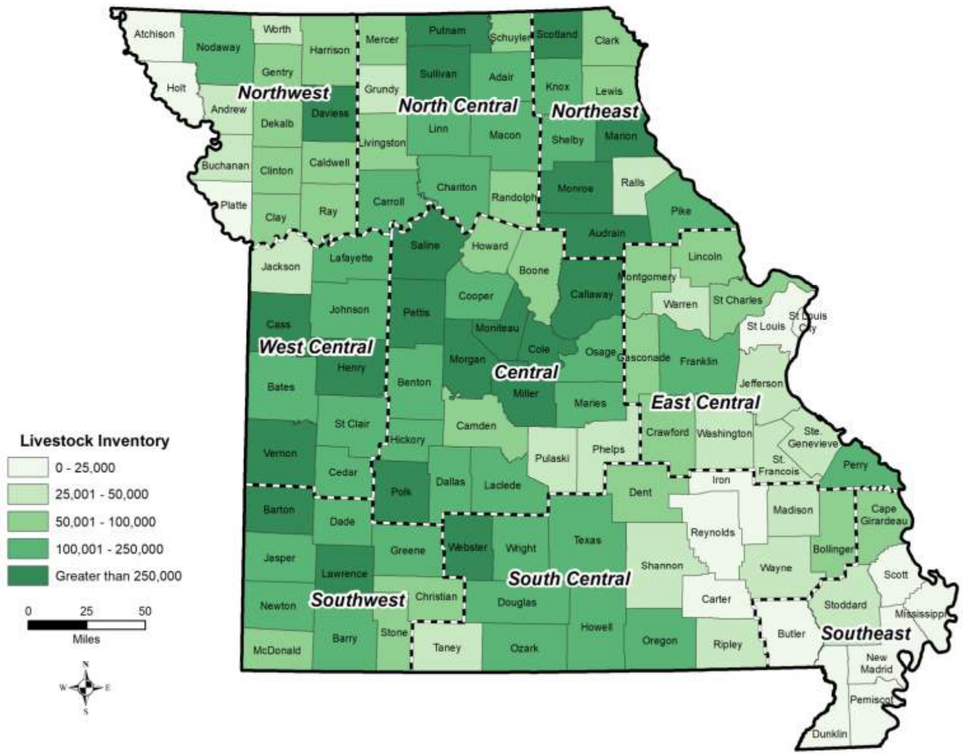


**Figure 4-7. Livestock Inventory by County**
*Source: 2017 USDA Census of Agriculture*

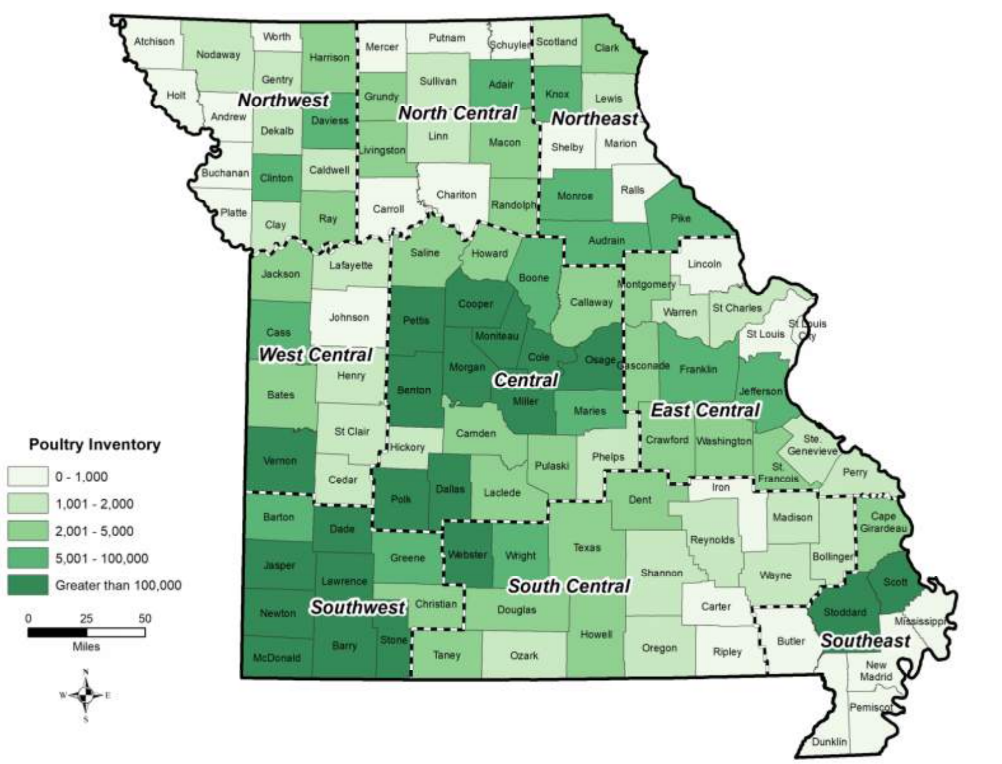


**Figure 4-8. Poultry Inventory by County**
*Source: 2017 USDA Census of Agriculture*

**Table 4-16** provides a summary of the potential for drought impacts in each region relative to the other regions. The potential for agricultural drought impacts by county is presented in **Appendix B**. Results are presented alphabetically by county and ranked by the overall potential for impact.

The Northeast Region has the most potential for impact to non-irrigated crop acres. The North Central, Northwest, West Central, and Southeast regions show above-average potential for impacts to non-irrigated crop acres, while the South Central Region has the least potential for impact. The Southwest and Central regions have the most potential for impact to both livestock and poultry, and the Southeast Region has the least potential for impact.

Combining the scores for non-irrigated crop acres, livestock and poultry inventories provides an overall agricultural potential relative impact score for each region. The average overall potential relative impact score for agriculture is provided for each region in **Table 4-16**. The Southwest Region has the highest relative potential impact to agriculture from drought, followed by the Northeast and West Central regions. The South Central, East Central, and Southeast regions have the lowest relative potential impact to agriculture from drought.

**Table 4-16. Relative Drought Impact Potential for Agriculture by Region**

| Region | Number of Counties | Average Crop Potential Impact Score (1–4) | Average Livestock Potential Impact Score (1–4) | Average Poultry Potential Impact Score (1–4) | Average Agricultural Potential Impact Score (1–4) |
|---|---|---|---|---|---|
| Central | 20 | 2.1 | 3.2 | 3.4 | 2.9 |
| East Central | 13 | 2.2 | 1.8 | 2.3 | 2.1 |
| North Central | 12 | 3.0 | 2.7 | 2.1 | 2.6 |
| Northeast | 10 | 3.7 | 3.1 | 2.1 | 3.0 |
| Northwest | 15 | 3.0 | 1.9 | 1.9 | 2.2 |
| South Central | 17 | 1.2 | 2.2 | 2.2 | 1.9 |
| Southeast | 8 | 3.1 | 1.3 | 1.9 | 2.1 |
| Southwest | 10 | 2.1 | 3.3 | 3.9 | 3.1 |
| West Central | 9 | 3.3 | 3.1 | 2.4 | 3.0 |

Note: Lower scores reflect lower relative potential impact.

## 4.3 Municipal Water Supply

For this analysis, municipal water use refers to public water systems, self-supplied residences, and self-supplied businesses. Water use among these water users in Missouri is detailed in the Missouri Water Resources Plan (MoDNR 2020). In the early stages of drought, public water system customers and self-supplied users experience browning lawns and landscapes. Some communities may tolerate browning lawns while others may increase irrigation practices to offset the drought impacts. The increase in summer irrigation puts an additional strain on water resources. During a drought, municipalities may ask for voluntary reductions in landscape irrigation or impose mandated restrictions with fines. Public water systems may have tiered water rates or drought surcharges to discourage excessive water use.

The responsiveness of customers to reducing water use is a function of their current level of water use, prior actions to conserve water, attitudes about water resources, and incentives. Customers are less likely to reduce essential water uses. Thus, systems with a low average per capita water use are likely to have less response to calls to conserve water than systems with a high average per capita water use. More affluent customers may be willing to pay the price of maintaining a green lawn, and some homeowner associations have covenants that require homeowners to maintain a green front lawn. Customers who have already

installed low-flow fixtures and implemented water-saving devices and practices may have less opportunity to conserve. A direct install program where the water system pays a contractor to replace old toilets and fix leaks will be more successful than a rebate program in which the homeowner gets a cost break on fixtures but must do the installations themselves.

As the severity of drought increases, water systems may, at their discretion, move to mandatory water use restrictions, such as banning all outdoor irrigation and limiting commercial water use. Nonresidential restrictions may include limiting services (e.g., only serving water in restaurants upon request), prohibiting services (e.g., closing car washes), or mandating a percent reduction in water use. Such restrictions may reduce business revenues, reduce wages earned, and reduce sales taxes, thus creating an economic ripple effect in the community.

During drought conditions, a water system may initially experience an increase in revenues as water demand increases and then incur a loss of revenue from imposed water use restrictions. In addition, the system may incur an increase in costs for media campaigns, public education, monitoring violations, and other diversions of staff from routine assignments. If alternative water sources are available, these alternative sources are typically available at a higher cost. Thus, water systems may be financially stressed by higher costs at a time of lower revenues during drought conditions. Some water utilities may have a drought surcharge built into their water rate structure in advance of a drought that (1) provides an incentive for customers to use less water, and (2) offsets some of the revenue lost during droughts.

A water system with an abundant water supply, large storage infrastructure, and alternative water sources will avoid drought damages for a longer period than a water system with a single water source and minimal storage capacity.

### 4.3.1 Assessing the Economic Impact of Drought on Municipal Water Suppliers

The economic impact of drought on municipalities and public water providers may vary with the severity of drought, length of drought, adequacy of water supply, and customer behavior and opinions. The economic impact can be determined from the estimated value of water to the customer, which is usually higher than what customers pay. One of the first estimates of the perceived dollar value of urban drought impacts was conducted in 1970. An estimate of less than $15 per capita per day for urban water service loss was reported from the 1962 to 1966 drought in Massachusetts (Russell 1970). This estimate would be equivalent to $98 in 2020 dollars.

In 1994, a survey was conducted with water customers in three cities in Colorado to estimate what users would be willing to pay for different levels of reliability (Howe 1994). In the two cities with low levels of system reliability, the willingness to pay was not sufficient to cover the cost of increasing reliability—customers were willing to risk the possibility of drought restrictions rather than pay higher water bills. The third city had a high level of system reliability; however, customers were willing to accept a lower level of reliability for lower water bills.

A survey of homeowners and businesses in Sydney, Australia, was conducted in 2005 to identify their willingness to pay to avoid water restrictions. The survey was conducted during a period of extended drought restrictions. Results showed that customers were unwilling to pay to avoid occasional summer watering restrictions and were willing to accept brown grass in public areas but were willing to pay up to 31 percent of their average water bill to avoid long-term severe restrictions on water use (Hensher 2005).

In 1993, a similar study was conducted in 10 California water districts among homeowners familiar with living under water use restrictions. The study found that customers were willing to tolerate mild drought conditions but willing to pay $11.67 per month (in 1993 dollars) to avoid a 10 percent reduction in water

supply every 10 years, or $16.92 per month to avoid a 50 percent reduction once every 20 years (Koss 2001). These respective monthly values are equivalent to $20.54 and $29.78 in 2020 dollars.

Public water systems may incur costs from an increased number of repairs to line breaks during drought because of land subsidence. As source water becomes scarce, fast response times to line breaks become critical for saving water and for public relations. Land subsidence can also result in damages to foundations and costly home repairs. Source water with poor water quality associated with quantity issues caused by drought may increase treatment costs. The Water Research Foundation Study *Drought Management in a Changing Climate: Using Cost-Benefit Analyses to Assist Drinking Water Utilities* summarized information on the costs and benefits of drought management practices among drinking water utilities (Blue et al. 2015). The report focuses on the costs and benefits to utilities of implementing drought management practices. The report concludes that it is difficult to compare costs among utilities because costs are site-specific, and that it is difficult to separate short-term management costs from long-term water resource management planning costs.

One study evaluated the economic cost of disruptions of urban water supply among 53 water utilities in California considering local differences in demand characteristics and utility pricing structures (Buck et al. 2015). The researchers used information on customer willingness to pay to avoid water shortages of 10, 20, and 30 percent in combination with the price the customer pays for water, the utility cost of service, and an estimated price elasticity to derive the change in price that would be necessary to equalize supply and demand given 10, 20, and 30 percent reductions of supply assuming that water rates would change concurrently with the supply shortage. The study found that an average single-family residential customer is willing to pay from $60 to $600 annually to avoid an annual shortage depending upon the size of the shortage and customer location. Results of the study estimated the price customers pay for water would increase 18 percent to avoid a 10 percent loss in annual water supply, 75 percent to avoid a 20 percent loss in annual supply, and 178 percent to avoid a 30 percent loss in annual water supply, assuming that the economic loss would be immediately passed on to customers.

FEMA estimates a 1-day loss of water service to have a cost to the economy of $114 per capita per day in the affected area in 2020 dollars (FEMA 2020). Based on this estimate of loss, **Table 4-17** shows the dollar per capita per day loss for decreasing levels of water supply loss of service.

**Table 4-17. Estimated Economic Loss per Capita per Day by Percent Loss of Water Supply**

| Percent Loss | $ per Capita per Day |
|---|---|
| 5% | $5.70 |
| 10% | $11.40 |
| 20% | $22.80 |
| 30% | $34.20 |
| 40% | $45.60 |
| 50% | $57.00 |
| 100% | $114.00 |

*Source: FEMA 2020*

Long-term drought can impact groundwater levels and thus impact self-supplied domestic water users and businesses. The economic value for reduced water supply for self-supplied domestic users may be similar to the estimates shown in **Table 4-17**.

### 4.3.2 Potential for Drought Impacts on Municipal Water Supply

Counties with more population served by municipal water systems and with higher municipal water demand have the potential to incur more impacts from drought than those counties with less population served by municipal systems and with lower municipal water demand.

The municipal population served and the municipal water demand for each county is available in the Missouri Water Resources Plan (MoDNR 2020). **Figure 4-9** is from the plan and shows the 2016 water demand among major water systems in each county.

The potential for municipal water supply impacts from drought in each county and region, relative to the other counties and regions of the state, can be developed by assigning values of 1 to 4 to the quartile rankings of the population served by municipal systems and the municipal water demand of each county, then averaging the scores by region. The 2020 population served and municipal water demand for each county was obtained from the Missouri Water Resources Plan (MoDNR 2020). The relative comparison of regions helps identify which regions could be impacted most by drought solely based on the size of municipal systems in each county and region. Comparing this to other factors, such as the likelihood of drought occurring in a region, the susceptibility of the region (e.g., availability of water sources), and the region's resilience to drought (e.g., amount of water storage, existence of drought plans, etc.) can help define overall vulnerability.

As shown in **Figure 4-9**, few counties have a municipal water supply demand greater than 100 million gallons per day (MGD). When the counties are ranked by total municipal water demand from largest to smallest, the 75th percentile is only 3.2 MGD and the median (50th percentile) is 1.5 MGD. Similarly, for the county population served, the 75th percentile is 26,533 and the median (50th percentile) is 12,647. As a result, any county with a population served greater than 26,533 or a demand greater than 3.2 MGD is scored in the top quartile. When the county scores are averaged by region, the West Central, Southeast, and Southwest regions show the highest potential for drought damages to municipal water supply. The South Central and Northeast regions show the least potential for drought damages.

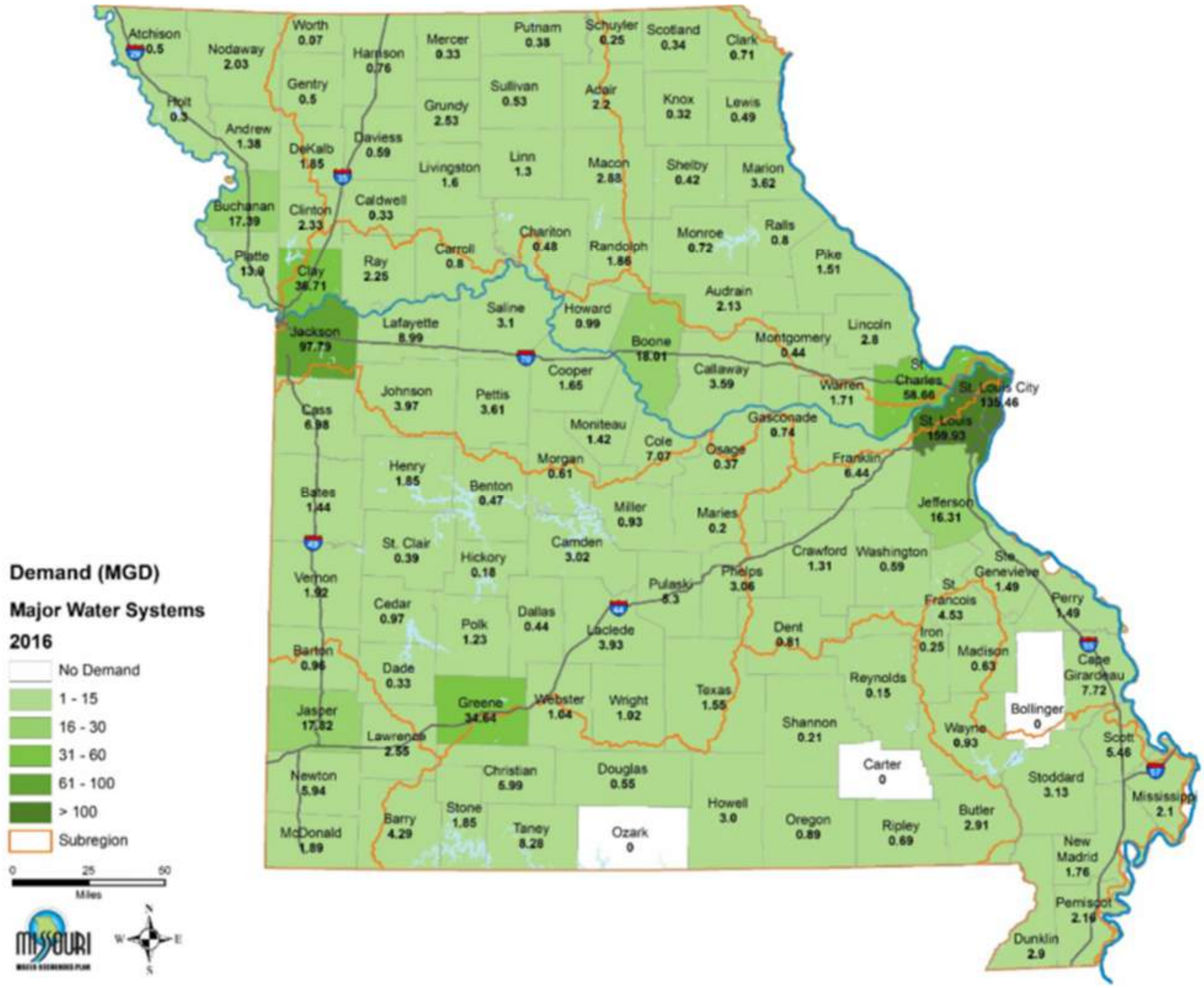


**Figure 4-9. 2016 Water Demand Among Major Water Systems**
*Source: MoDNR 2020*

**Table 4-18** provides a summary of the potential for drought impacts to municipal water supply in each region relative to the other regions. The potential impacts by county are presented in **Appendix B**. Results are presented alphabetically by county and ranked by overall potential for impact.

**Table 4-18. Relative Drought Impact Potential for Municipal Water Supply by Region**

| Region | Population Served Potential Impact (1–4) | Municipal Demand Potential Impact Score (1–4) | Average Municipal Potential Impact Score (1–4) |
|---|---|---|---|
| Central | 2.7 | 2.6 | 2.7 |
| East Central | 2.9 | 2.8 | 2.9 |
| North Central | 2.0 | 2.0 | 2.0 |
| Northeast | 1.9 | 1.9 | 1.9 |
| Northwest | 2.5 | 2.3 | 2.4 |
| South Central | 1.8 | 1.8 | 1.8 |
| Southeast | 3.4 | 3.3 | 3.3 |
| Southwest | 2.8 | 3.2 | 3.0 |
| West Central | 3.1 | 3.0 | 3.1 |

Note: Lower scores reflect lower relative potential impact.

## 4.4 Industrial Water Use

In 1991, the California Urban Water Agencies conducted a survey of 640 large water-using industries with high numbers of employees asking how plants would be affected by hypothetical water shortages of 15 and 30 percent. In most cases, plants would reduce plant output and reduce employment. The hypothetical 30 percent reduction in water supply was estimated to have a total impact of $11.8 billion in production losses in 1990 dollars (Wade 1991). This would be equivalent to $23 billion in 2020 dollars. In addition, a 30 percent reduction in water supply would result in a layoff of 5 percent of the workforce, and 26 percent of respondents would consider relocation. The study found that:

- Water had been considered a low-cost input until treatment and disposal costs increased.
- Limited water supplies can constrain production during droughts.
- Process water recycling was the focus of most conservation efforts.
- Easy and low-cost opportunities to save water had been exploited.
- Facilities that use high volumes of water have the most to lose during a shortage and were doing the most to reduce water use.
- A facility that has made substantial investments in conservation may have few remaining alternatives in response to a shortage other than cutting production.

A recent study of industrial water use by the Georgia Environmental Protection Division (GAEPD) included stakeholder groups representing paper and forest products, manufacturing, mining, and food processing (GAEPD 2020). These industrial sectors were found to be the largest industrial water users in the state based on an analysis of surface and groundwater withdrawal permits. Discussions among the stakeholder groups concluded that:

- Water was a valuable resource and critical to production.
- Water use varies with changes in the production process, which is dictated by market conditions.
- Water use among industries had dropped significantly over the last decade because of advanced recycling and other water use efficiency measures.
- Most large industries strive to use natural resources sustainably.

Many industrial facilities are willing to invest in water conservation at a unit cost (e.g., cost per 1,000 gallons) that is higher than the unit cost of their current water supply, which reflects a willingness to pay a premium for increased water reliability—management is willing to invest in efforts that minimize the risk of production interruptions.

In the short-term, a water shortage may limit production, postpone capital investments, and cause temporary unemployment. In the long-term, water shortages may result in industry relocation and loss of local employment.

Manufacturing in Missouri represents 12 percent or $39.8 billion of the 2019 total gross state product and accounts for 13.6 percent of the state's private sector employment, with over 277,000 jobs. In 2018, the manufacturing payroll in Missouri was $16.5 billion (Missouri Economic Research and Information Center 2019). **Table 4-19** lists 2019 industrial employment in Missouri by industry sector (U.S. Census Bureau 2019). This includes manufacturing, forestry and mining employment. Transportation equipment (i.e., automobiles), food, machinery, and fabricated metal products make up over half of the employment in the industrial sector.

According to USGS, self-supplied industries in 47 counties used 85 MGD, and self-supplied mining operations in 81 counties used 30 MGD in 2015 (USGS 2015). This does not include industrial water use supplied by public water systems. **Table 4-20** shows the top 10 counties in Missouri by industrial and

mining water use. The top 10 counties for industrial water use account for 83 percent of industrial use, with Jackson and Cape Girardeau counties accounting for more than half of the state's industrial water use. The top 10 counties for mining water use account for 79 percent of industrial use in the state.

Industrial and mining water use data by county in MGD, as provided by USGS, is used to estimate the potential for industrial impacts from drought in each county relative to other counties by assigning values of 1 to 4 to the rankings of water use.

Not all counties have reported industrial and/or mining water use. Forty-seven counties in Missouri have industrial water use, which is less than half of the counties. Those counties without industrial water use are assigned a score of 1, counties with industrial water use up to 0.5 MGD are assigned a value of 2, counties with industrial water use of 0.5 to 1.0 MGD are assigned a value of 3, and counties with industrial water use greater than 1.0 MGD are assigned a value of 4.

More counties have mining water use than have industrial water use even though many have very low water use. Those counties without mining water use are assigned a score of 1, counties with mining water use up to 0.04 MGD are assigned a value of 2, counties with water use from 0.04 to 0.1 MGD are assigned a value of 3, and counties with mining water use greater than 0.1 MGD are assigned a value of 4.

Each county has an overall score, which is the sum of the industrial and mining water use scores. The scores by county are listed in **Appendix B**, as is a table of counties ranked by overall score. County scores are then averaged by region, as shown in **Table 4-21**. By region, the Southwest has the highest relative potential for drought damages for industry. The East Central Region has the highest relative potential for drought damages for mining, as well as for industry and mining combined.

**Table 4-19. Missouri Industrial Employment, 2019**

| Sector | Number of Employees |
|---|---|
| Transportation Equipment Manufacturing | 49,080 |
| Food Manufacturing | 40,623 |
| Machinery Manufacturing | 34,756 |
| Fabricated Metal Product Manufacturing | 31,478 |
| Miscellaneous Manufacturing | 22,208 |
| Chemical Manufacturing | 19,413 |
| Plastics and Rubber Products Manufacturing | 14,972 |
| Electrical Equipment, Appliance, and Component Manufacturing | 10,466 |
| Nonmetallic Mineral Product Manufacturing | 8,869 |
| Paper Manufacturing | 8,630 |
| Wood Product Manufacturing | 7,226 |
| Computer and Electronic Product Manufacturing | 6,519 |
| Furniture and Related Product Manufacturing | 6,322 |
| Beverage and Tobacco Product Manufacturing | 6,321 |
| Primary Metal Manufacturing | 6,199 |
| Mining, Quarrying, and Oil and Gas Extraction | 3,518 |
| Textile Product Mills | 1,511 |
| Apparel Manufacturing | 1,199 |
| Petroleum and Coal Products Manufacturing | 1,188 |
| Textile Mills | 484 |
| Forestry and Logging | 234 |
| **Manufacturing, Forestry, and Mining Total** | **281,216** |

*Source: U.S. Census Bureau 2019*

**Table 4-20. Top 10 Missouri Counties with Industrial and Mining Water Use**

| Industrial | | Mining | |
|---|---|---|---|
| County | MGD | County | MGD |
| Jackson | 32.65 | Callaway | 4.70 |
| Cape Girardeau | 16.83 | Reynolds | 4.52 |
| Jasper | 4.22 | Ste. Genevieve | 3.94 |
| Clay | 4.13 | St. Louis | 3.57 |
| McDonald | 3.09 | Jefferson | 2.20 |
| Pettis | 2.23 | Jackson | 1.32 |
| Marion | 2.09 | Iron | 1.23 |
| Ste. Genevieve | 1.89 | Stoddard | 0.69 |
| Taney | 1.78 | Cape Girardeau | 0.66 |
| Washington | 1.66 | Platte | 0.63 |

*Source: USGS 2015*

**Table 4-21. Relative Drought Impact Potential for Industry by Region**

| Region | Industry Potential Impact Score (1–4) | Mining Potential Impact Score (1–4) | Average Industrial Potential Impact Score (1–4) |
|---|---|---|---|
| Central | 1.7 | 2.6 | 2.1 |
| East Central | 2.2 | 3.5 | 2.5 |
| North Central | 1.5 | 1.4 | 1.7 |
| Northeast | 1.7 | 2.0 | 2.1 |
| Northwest | 1.4 | 2.1 | 1.8 |
| South Central | 1.4 | 2.6 | 2.0 |
| Southeast | 2.1 | 2.3 | 2.2 |
| Southwest | 2.4 | 2.5 | 2.5 |
| West Central | 1.7 | 2.2 | 1.9 |

Note: Lower scores reflect lower relative potential impact.

## 4.5 Power Production

Electric energy (power) is generated in Missouri from hydropower, thermoelectric power (coal, natural gas, petroleum, and nuclear), and renewable energy. **Figure 4-10** shows the 2019 generation capacity by county and fuel type for the major electric utility generating facilities in the state (U.S. Department of Energy, Energy Information Administration [EIA] 2019). Generation capacity is based on summer capacity, which can be lower than the nameplate capacity because of reduced cooling efficiency in summer months. Drought is most likely to impact power production in summer months, so the summer generating capacity is the most relevant attribute for this analysis.

**Figure 4-11** shows historical generation in gigawatt-hours (GWh) by type of power generation (EIA 2019). Petroleum was excluded because of its small amount of generation relative to other fuel types. Coal-fired generation has dominated power generation in the state, but in recent years, coal generation has declined as natural gas generation and renewable energy sources have increased. However, coal still accounted for more than 70 percent of statewide power generation in 2019.

**Table 4-22** shows power generation by generation type and region in 2019 (EIA 2019). The East Central Region produces the most power, followed by the Northwest and Central regions. The East Central Region has the most coal generation. The only nuclear generating facility is in the Central Region. The Central Region also generates the most hydropower, followed by the South Central Region. The Northwest Region produces the most power from renewable energy sources (not including hydropower).

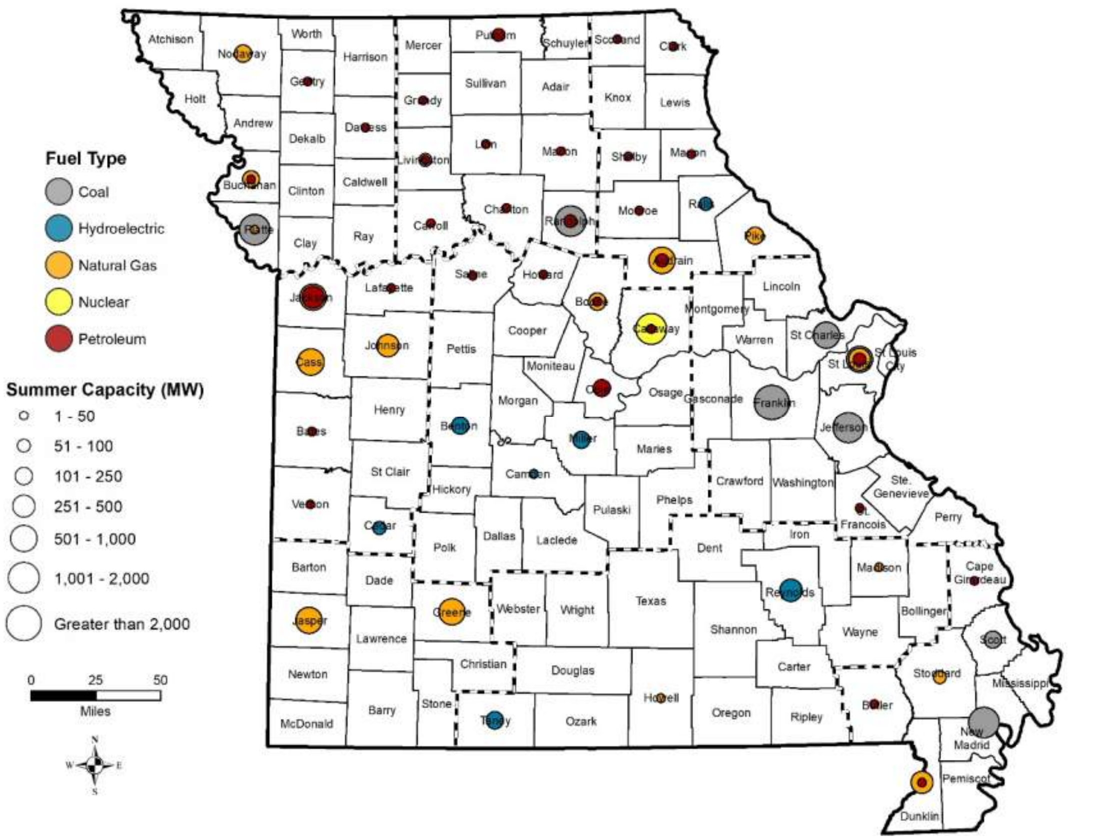


**Figure 4-10. Power Generation by County in Missouri**
*Source: EIA 2019*

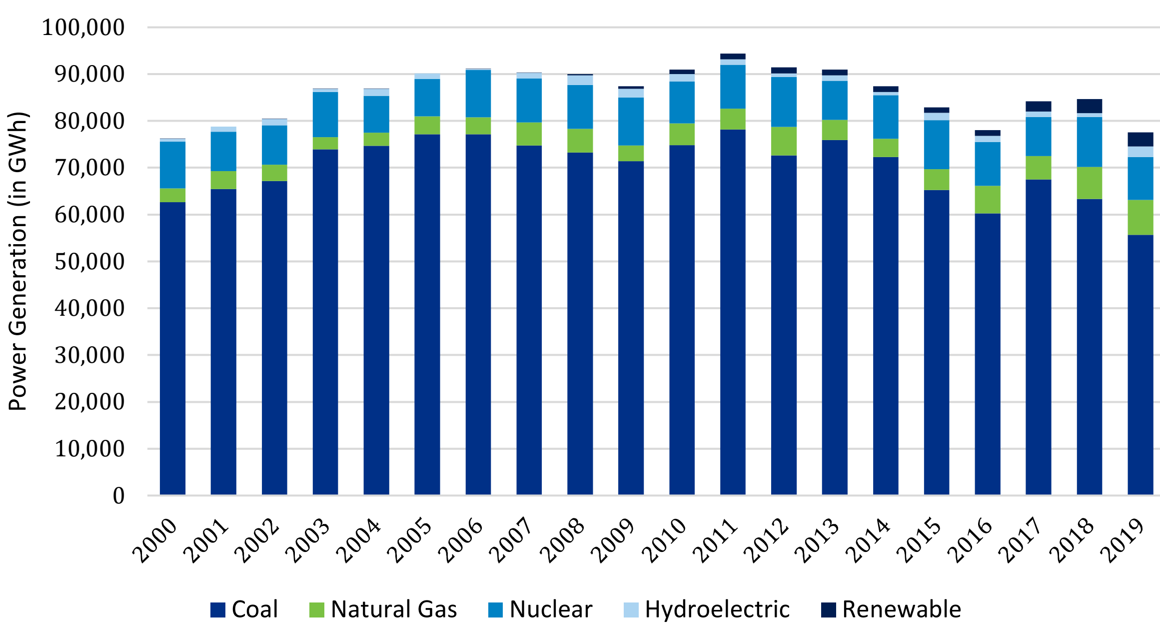


**Figure 4-11. Missouri Power Generation by Energy Source, 2000 to 2020**
*Source: EIA 2019*

**Table 4-22. Power Generation in Missouri by Region and Fuel Type, 2019 (MWh)**

| Region | Hydropower | Nuclear | Coal | Natural Gas | Renewable | Total |
|---|---|---|---|---|---|---|
| Central | 1,476,213 | 9,189,863 | 0 | 35,481 | 52,894 | 10,754,452 |
| East Central | 0 | 0 | 24,052,525 | 15,909 | 10,342 | 24,078,776 |
| North Central | 0 | 0 | 8,122,252 | 4,414 | 12,424 | 8,139,090 |
| Northeast | 153,782 | 0 | 0 | 195,241 | 0 | 349,023 |
| Northwest | 0 | 0 | 8,562,278 | 31,534 | 2,864,184 | 11,457,996 |
| South Central | 849,210 | 0 | 0 | 5,885 | 21,497 | 876,592 |
| Southeast | 0 | 0 | 8,499,230 | 1,041,487 | 0 | 9,540,717 |
| Southwest | 0 | 0 | 2,576,728 | 3,068,293 | 32,840 | 5,677,861 |
| West Central | 72,739 | 0 | 2,913,654 | 2,948,070 | 36,338 | 5,970,801 |
| **STATE TOTAL** | **2,551,944** | **9,189,863** | **54,726,667** | **7,346,314** | **3,030,519** | **76,845,307** |

MWh = megawatt-hours
Totals may not add up because of rounding.
*Source: EIA Form 923*

The timing and availability of water plays an important role in power generation. Hydropower generation uses river flow at impoundments to turn the generating turbines. Hydropower generation can be impacted by low-flows during drought conditions. Large coal-fired, natural gas-fired, and nuclear generators heat water to create steam to turn turbines and use large volumes of water to condense the steam back to water. Older generating facilities use once-through cooling, which withdraws and returns large volumes of water. Some generating facilities use cooling towers that withdraw large volumes of water, most of which is evaporated off from the towers. Newer technology using compressed gas to turn turbines requires much less water, if any. Data from **Table 4-22** shows that the Central and South Central regions have significant hydropower generation. Each of these facilities is associated with a reservoir and therefore may be impacted by low lake level conditions during drought.

Cooling water requirements to generate one MWh of power vary widely. Requirements range from over 40,000 gallons per MWh for a coal-fired generating unit with once-through cooling, to about 1,200 gallons per MWh for a nuclear or coal-fired generating unit with a cooling tower, to 225 gallons per MWh for a natural gas combined-cycle generating unit, to zero water use for a gas combustion turbine (National Renewable Energy Laboratory [NREL] 2011). Large thermoelectric generating facilities using large volumes of water for cooling typically use surface water. Thus, low-flow conditions may limit power generation during drought conditions.

EIA data was used to analyze 2019 power generation in Missouri (EIA 2019). **Table 4-23** shows the EIA 2019 generation data in MWh by type and district for facilities that rely on surface water. **Table 4-24** shows the corresponding annual water withdrawals in millions of gallons (MG) based on EIA data. Power generation using surface water for cooling is the most vulnerable to disruptions from low-flow conditions in the East Central Region. **Table 4-25** shows the 2019 annual water withdrawal, consumption, and discharge by region (EIA 2019). Power generation in the East Central and West Central regions uses once-through cooling and therefore reports the same discharge volume as the volume of water withdrawn.

Renewable energy, such as wind and solar power, does not have water requirements. Power generation from pumped storage, such as the Taum Sauk facility, recycles the water used to generate hydropower and only requires water to make up evaporative losses.

**Table 4-23. Power Generation Using Surface Water Cooling by Region and Fuel Type, 2019 (MWh)**

| Region | Nuclear | Coal | Natural Gas | Total |
|---|---|---|---|---|
| Central | 9,189,863 | 0 | 0 | 9,189,863 |
| East Central | 0 | 24,032,892 | 16,014 | 24,048,906 |
| North Central | 0 | 8,122,252 | 0 | 8,122,252 |
| Northeast | 0 | 0 | 0 | 0 |
| Northwest | 0 | 8,566,329 | 5,927 | 8,572,256 |
| South Central | 0 | 0 | 0 | 0 |
| Southeast | 0 | 6,880,553 | 0 | 6,880,553 |
| Southwest | 0 | 0 | 0 | 0 |
| West Central | 0 | 2,913,654 | 26,852 | 2,940,506 |
| **STATE TOTAL** | **9,189,863** | **50,515,680** | **48,793** | **59,754,336** |

Totals may not add up because of rounding.
*Source: EIA Forms 860 and 923*

**Table 4-24. Surface Water Withdrawals by Region and Fuel Type, 2019 (MG)**

| Region | Nuclear | Coal | Natural Gas | Total |
|---|---|---|---|---|
| Central | 7,833 | 0 | 0 | 7,833 |
| East Central | 0 | 1,041,795 | 848 | 1,042,643 |
| North Central | 0 | 285,660 | 0 | 285,660 |
| Northeast | 0 | 0 | 0 | 0 |
| Northwest | 0 | 122,628 | 4,458 | 127,087 |
| South Central | 0 | 0 | 0 | 0 |
| Southeast | 0 | 303 | 0 | 303 |
| Southwest | 0 | 0 | 0 | 0 |
| West Central | 0 | 85,648 | 8,801 | 94,449 |

Totals may not add up because of rounding.
*Source: EIA Forms 860 and 923*

**Table 4-25. Surface Water Use by Region for Power Generation Cooling, 2019 (MG)**

| Region | Withdrawals | Discharge | Consumption |
|---|---|---|---|
| Central | 7,833 | 1,757 | 6,077 |
| East Central | 1,042,643 | 1,042,643 | 0 |
| North Central | 285,660 | 285,320 | 286 |
| Northeast | 0 | 0 | 0 |
| Northwest | 127,087 | 123,772 | 2,759 |
| South Central | 0 | 0 | 0 |
| Southeast | 303 | 301 | 2 |
| Southwest | 0 | 0 | 0 |
| West Central | 94,449 | 94,449 | 0 |
| **STATE TOTAL** | **1,557,974** | **1,548,243** | **9,123** |

Discharge plus consumption may not total to withdrawals because of rounding or missing data.
*Source: EIA Forms 860 and 923*

Drought conditions and high temperatures not only increase the demand for power but can reduce the capacity to generate power. In late 2012, according to the USACE, six hydropower plants on the Missouri River (upstream of Missouri) produced 569 million kilowatt-hours (kWh), approximately 110 million kWh less than the average December energy production. Drought conditions resulted in diminished flow in the Missouri River, yielding less hydropower production.

In 2012, low water levels on the Mississippi River forced the Associated Electric Cooperative to deploy diesel-powered pumps at the New Madrid (coal-fired) Power Plant in the Southeast Region to maintain electricity supply to approximately 660,000 homes, farms, and businesses. Use of the diesel pumps maintained operation of the power plant but significantly increased costs at a time when financial strain on farmers was already causing widespread hardship (MoDNR 2013).

FEMA estimates a 1-day loss of electric service to have a cost to the economy of $174 per capita per day in 2020 dollars (FEMA 2020). During conditions when the demand for electricity is greater than the available supply, electric utilities may ask customers to reduce their electric usage by using measures such as turning off air conditioners to avoid brown-outs, or electric customers may experience a complete loss of power lasting from a few minutes to hours. From the FEMA estimate for a 24-hour loss, it is assumed that a 12-hour loss would cost $87 per person per day and a 1-hour loss would cost $7.25 per person per day. These estimates of loss can be multiplied by the population impacted by the reduction in service within a county, region, or state. **Table 4-26** provides an example of the economic cost in millions of dollars of a loss of electric service for an increasing percent of the Missouri 2020 state population. For example, a 6-hour loss of electric service for 5 percent of the state population is estimated to cost $13.39 million. Similar estimates can be derived by county or region.

While power-generating facilities are in specific counties, the power generated and the impact of a reduction in power generation is distributed across a larger network through the power grid. Thus, the relative potential for drought impacts cannot be determined at the county or even regional level.

**Table 4-26. Economic Cost of Loss of Power Service (Million 2020 Dollars)**

| Percent of Population Impacted | Disruption of Service | | | | |
|---|---|---|---|---|---|
| | 1 Hour | 3 Hour | 6 Hour | 12 Hour | 24 Hour |
| **5%** | $2.23 | $6.69 | $13.39 | $26.77 | $53.55 |
| **10%** | $4.46 | $13.39 | $26.77 | $53.55 | $107.10 |
| **15%** | $6.69 | $20.08 | $40.16 | $80.32 | $160.65 |
| **20%** | $8.92 | $26.77 | $53.55 | $107.10 | $214.19 |
| **25%** | $11.16 | $33.47 | $66.94 | $133.87 | $267.74 |
| **30%** | $13.39 | $40.16 | $80.32 | $160.65 | $321.29 |
| **35%** | $15.62 | $46.85 | $93.71 | $187.42 | $374.84 |
| **40%** | $17.85 | $53.55 | $107.10 | $214.19 | $428.39 |
| **45%** | $20.08 | $60.24 | $120.48 | $240.97 | $481.94 |
| **50%** | $22.31 | $66.94 | $133.87 | $267.74 | $535.49 |

## 4.6 Tourism and Recreation

Drought damages to the tourism and recreation sector of the economy are generally indirect effects of drought. Recreational activities such as fishing, tubing, camping, and hiking can be impacted by low-flow water conditions. In extremely dry conditions, access to recreational areas can be restricted or limited. This in turn impacts the local economies that service the tourism and recreational activities, such as hotels, restaurants, rental and guide companies, and golf courses.

Annual reports from the Missouri Division of Tourism provides annual totals of tourism-related expenditures, employment, and state sales tax revenue by county (Missouri Division of Tourism 2021). County-level data from these reports for 2011 to 2020 are summarized by region in **Tables 4-27** through **4-29.** The annual summaries are shown in **Figures 4-12** through **4-14**.

Tourism-related expenditures and sales tax revenue during the drought year of 2012 were higher than in 2011 and slightly higher than in 2013. Tourism-related expenditures and sales tax revenue in 2018 were lower than in either 2017 or 2019. However, there does not appear to be a direct correlation between tourism dollars and drought conditions.

The ranking of regions by tourism-related expenditures and state sales tax revenue remains the same over the 2011 to 2020 period, with the East Central Region generating the most tourism revenue, followed by the West Central and Southwest regions. The Northeast and North Central regions generated the least tourism and state sales tax revenue.

As with tourism revenue, the East Central Region consistently has the highest tourism-related employment while the Northeast has the lowest. Statewide tourism-related employment in 2012 was higher than in 2011 by 1,700 employees. Tourism employment declined after 2017; however, other factors, such as changes in economic conditions, could have had as much if not more impact than drought on tourism-related expenditures and jobs. The 2020 decrease in tourism expenditures, revenue, and employment is a reflection of the COVID-19 pandemic.

**Table 4-27. Total Tourism-Related Expenditures (Million 2020 Dollars)**

| Region | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Central | $1,151 | $1,185 | $1,176 | $1,193 | $1,253 | $1,294 | $1,292 | $1,298 | $1,323 | $1,263 |
| East Central | $4,870 | $5,169 | $5,178 | $5,411 | $5,675 | $5,867 | $5,865 | $5,772 | $6,005 | $5,238 |
| North Central | $137 | $138 | $127 | $132 | $136 | $139 | $139 | $140 | $140 | $139 |
| Northeast | $106 | $109 | $107 | $109 | $115 | $118 | $116 | $120 | $122 | $122 |
| Northwest | $983 | $1,014 | $1,016 | $1,033 | $1,088 | $1,134 | $1,129 | $1,191 | $1,109 | $1,039 |
| South Central | $687 | $683 | $671 | $684 | $727 | $758 | $765 | $790 | $789 | $712 |
| Southeast | $408 | $419 | $420 | $419 | $435 | $454 | $453 | $431 | $430 | $422 |
| Southwest | $1,230 | $1,268 | $1,270 | $1,297 | $1,390 | $1,453 | $1,442 | $1,480 | $1,515 | $1,427 |
| West Central | $2,019 | $2,113 | $2,111 | $2,211 | $2,500 | $2,612 | $2,573 | $2,451 | $2,545 | $2,275 |
| **STATE TOTAL** | **$11,590** | **$12,099** | **$12,077** | **$12,488** | **$13,319** | **$13,828** | **$13,774** | **$13,672** | **$13,980** | **$12,635** |

Totals may not add up because of rounding.
*Source: Missouri Division of Tourism 2021*

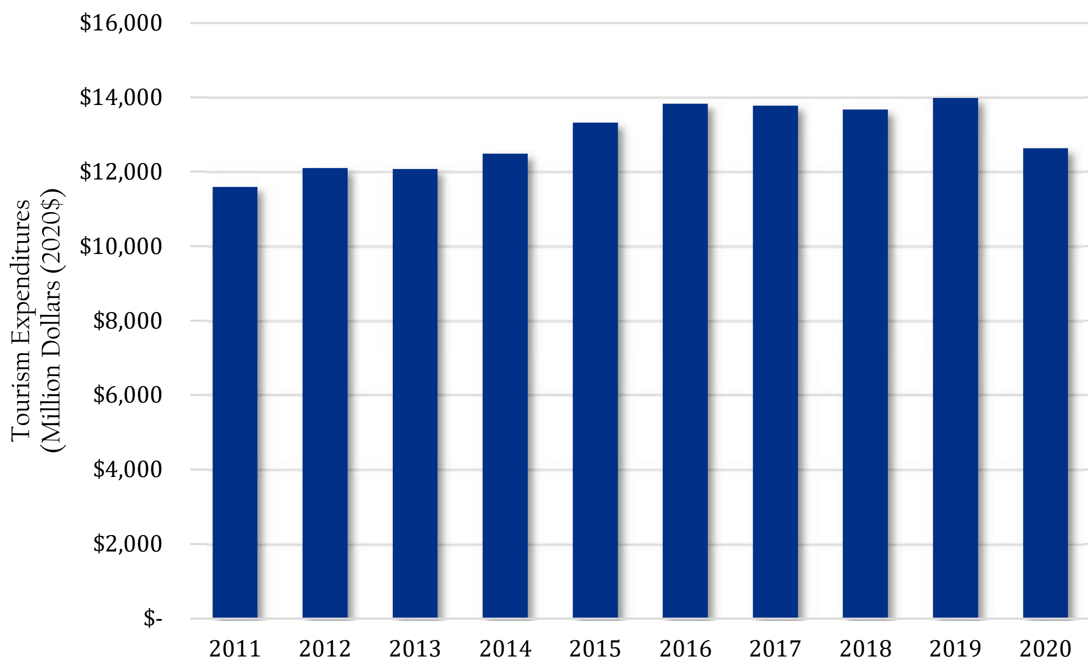


**Figure 4-12. Annual Tourism-Related Expenditures (Millions of 2020 dollars)**
*Source: Missouri Division of Tourism 2021*

**Table 4-28. Total Tourism-Related State Sales Tax (Million 2020 Dollars)**

| Region | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Central | $49 | $50 | $50 | $50 | $53 | $55 | $55 | $55 | $56 | $53 |
| East Central | $206 | $218 | $219 | $229 | $240 | $248 | $248 | $244 | $254 | $221 |
| North Central | $6 | $6 | $5 | $6 | $6 | $6 | $6 | $6 | $6 | $6 |
| Northeast | $4 | $5 | $5 | $5 | $5 | $5 | $5 | $5 | $5 | $5 |
| Northwest | $42 | $43 | $43 | $44 | $46 | $48 | $48 | $50 | $47 | $44 |
| South Central | $29 | $29 | $28 | $29 | $31 | $32 | $32 | $33 | $33 | $30 |
| Southeast | $17 | $18 | $18 | $18 | $18 | $19 | $19 | $18 | $18 | $18 |
| Southwest | $52 | $54 | $54 | $55 | $59 | $61 | $61 | $63 | $64 | $60 |
| West Central | $85 | $89 | $89 | $93 | $106 | $110 | $109 | $104 | $108 | $96 |
| **STATE TOTAL** | **$490** | **$511** | **$510** | **$528** | **$563** | **$584** | **$582** | **$578** | **$591** | **$534** |

Totals may not add up because of rounding
*Source: Missouri Division of Tourism 2021*

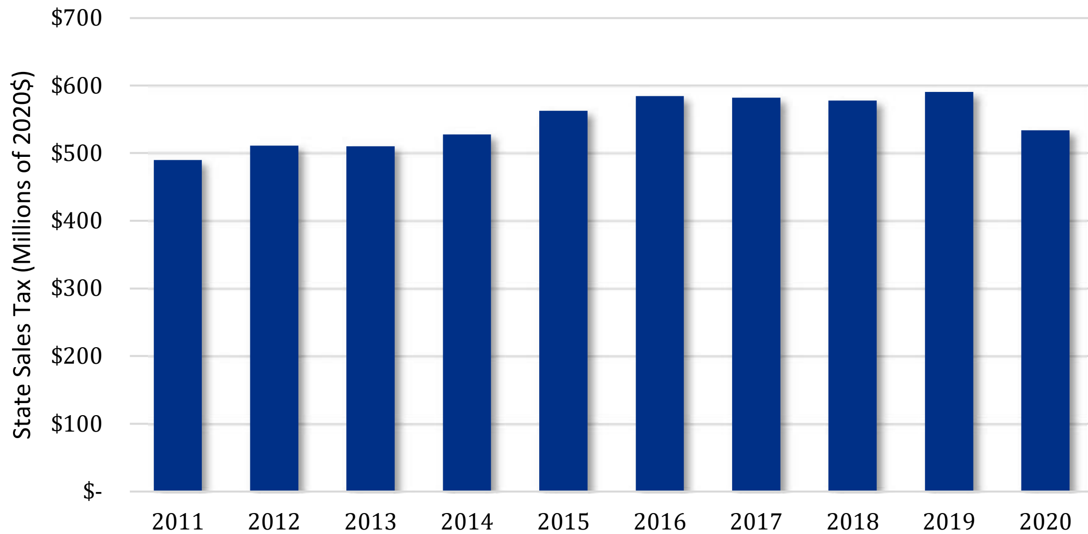


**Figure 4-13. Annual Tourism-Related State Sales Tax (Millions of 2020 dollars)**
*Source: Missouri Division of Tourism 2021*

**Table 4-29. Total Tourism-Related Employment (Thousand Employees)**

| Region | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Central | 31.7 | 31.7 | 31.8 | 32.6 | 33.0 | 33.9 | 34.8 | 33.1 | 33.2 | 31.3 |
| East Central | 117.3 | 117.4 | 119.1 | 121.5 | 125.4 | 130.3 | 132.1 | 126.2 | 126.7 | 114.2 |
| North Central | 4.0 | 4.0 | 4.0 | 4.1 | 4.0 | 4.0 | 4.1 | 3.9 | 3.9 | 3.6 |
| Northeast | 3.3 | 3.2 | 3.2 | 3.3 | 3.3 | 3.5 | 3.4 | 3.2 | 3.1 | 3.0 |
| Northwest | 24.1 | 24.4 | 25.2 | 25.4 | 25.4 | 25.9 | 26.4 | 25.6 | 25.7 | 24.0 |
| South Central | 17.4 | 17.0 | 17.2 | 17.1 | 17.4 | 18.0 | 18.5 | 18.3 | 18.0 | 16.2 |
| Southeast | 9.3 | 9.4 | 9.5 | 9.6 | 9.7 | 10.1 | 10.3 | 10.1 | 10.0 | 9.5 |
| Southwest | 28.5 | 28.9 | 29.3 | 30.2 | 30.5 | 31.8 | 32.4 | 31.5 | 33.1 | 31.4 |
| West Central | 44.0 | 45.3 | 45.8 | 47.0 | 48.3 | 50.4 | 51.3 | 50.0 | 50.6 | 46.5 |
| **STATE TOTAL** | **279.6** | **281.3** | **285.1** | **290.7** | **297.1** | **307.9** | **313.4** | **301.8** | **304.3** | **279.6** |

Totals may not add up because of rounding.
*Source: Missouri Division of Tourism 2021*

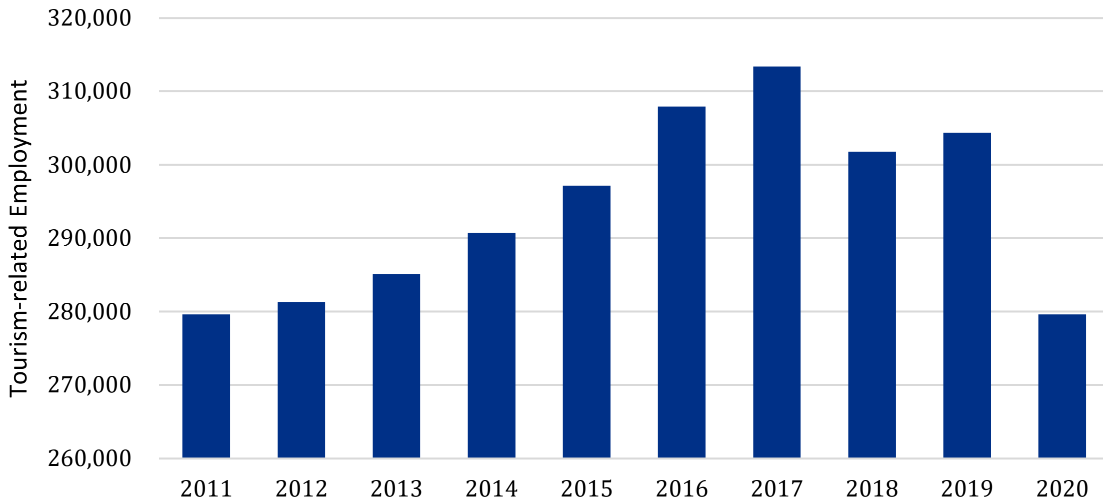


**Figure 4-14. Annual Tourism-Related Employment**
*Source: Missouri Division of Tourism 2021*

Annual data on the number of hunting and fishing licenses sold from 2010 to 2020 were obtained from the Missouri Department of Conservation (MDC) (2021). The annual sales of licenses are shown in **Figure 4-15**. The number of fishing licenses sold per year does not indicate a significant impact from drought in either 2012 or 2018 (MDC 2021). Similarly, the number of hunting licenses sold per year does not suggest a significant impact from drought conditions. This may be because of licenses being renewed on an annual basis regardless of current climate conditions.

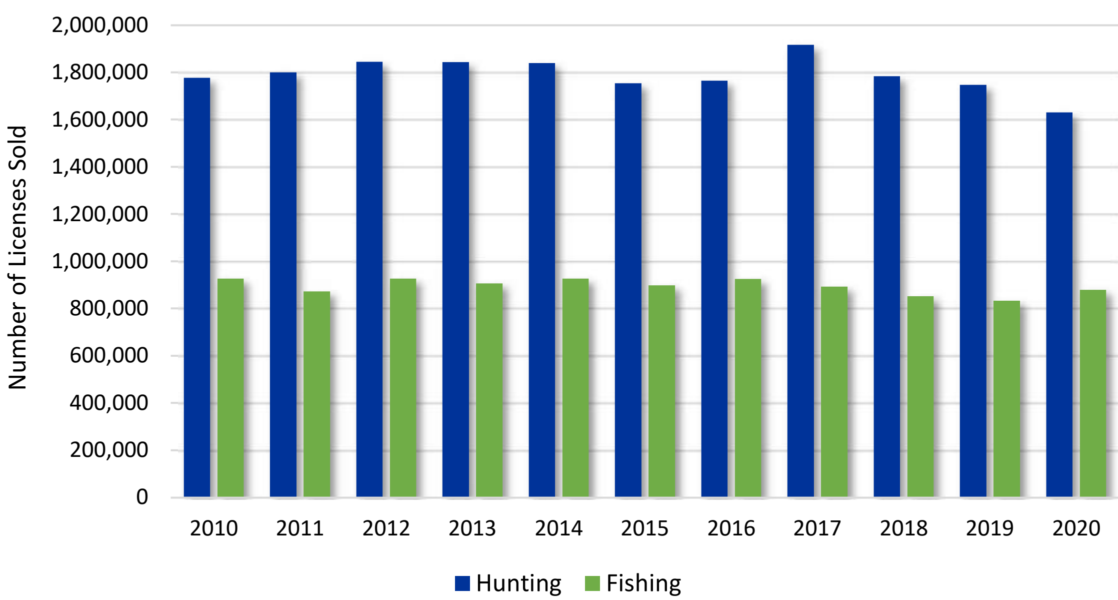


**Figure 4-15. Annual Sales of Hunting and Fishing Licenses**
*Source: Missouri Department of Conservation 2021*

Information on visitation at state parks and historical sites was obtained from the MoDNR Division of State Parks. **Figure 4-16** shows the annual number of visitor days in millions from 2011 to 2020. The fluctuation in park visitors does not correlate with drought conditions. The 2019 decrease in visitation is likely due to flooding that occurred that year.

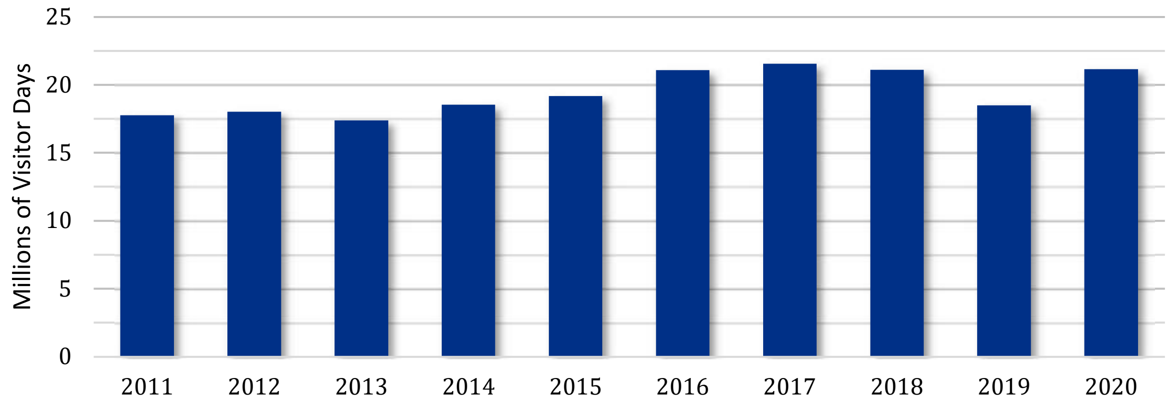


**Figure 4-16. Annual Number of Millions of Visitor Days to Missouri State Parks**
*Source: Missouri DNR 2021*

The number of state parks by region and the number of millions of visitor days by year from 2011 to 2020 by region are shown in **Table 4-30**. The Central, East Central, and South Central regions account for 60 percent of the state parks and 75 percent of the annual visitor days. These regions are more likely to see economic impacts of park closures or lower visitation owing to drought conditions and fire hazards where low water levels and fire bans discourage visitors. The Southeast Region has the fewest number of annual visitor days and is therefore less likely to see economic impacts of reduced state park visits. However, it appears that economic conditions and environmental conditions other than drought may have a more significant impact on park visitors than drought conditions.

**Table 4-30. Missouri State Park Visitors by District and Year (Million Visitor Days)**

| Region | Parks | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Central | 20 | 4.87 | 5.01 | 4.72 | 4.88 | 5.19 | 5.19 | 5.54 | 5.74 | 4.84 | 4.51 |
| East Central | 27 | 5.13 | 5.24 | 4.84 | 5.01 | 5.12 | 5.90 | 5.85 | 5.46 | 4.82 | 6.02 |
| North Central | 7 | 1.02 | 1.06 | 1.04 | 0.97 | 1.07 | 1.03 | 1.04 | 1.03 | 1.14 | 1.67 |
| Northeast | 6 | 0.53 | 0.49 | 0.49 | 0.67 | 0.62 | 0.71 | 0.82 | 0.59 | 0.42 | 0.67 |
| Northwest | 6 | 1.06 | 0.98 | 0.94 | 1.14 | 1.32 | 1.39 | 1.51 | 1.10 | 0.83 | 0.96 |
| South Central | 17 | 3.48 | 3.43 | 3.79 | 4.13 | 4.07 | 4.79 | 4.61 | 4.23 | 3.90 | 4.48 |
| Southeast | 6 | 0.29 | 0.43 | 0.26 | 0.23 | 0.21 | 0.28 | 0.33 | 0.25 | 0.21 | 0.27 |
| Southwest | 8 | 0.67 | 0.63 | 0.64 | 0.70 | 0.72 | 0.81 | 0.80 | 1.71 | 1.49 | 1.58 |
| West Central | 11 | 0.71 | 0.75 | 0.68 | 0.80 | 0.85 | 0.97 | 1.07 | 1.00 | 0.82 | 0.99 |
| **STATE TOTAL** | **108** | **17.77** | **18.02** | **17.38** | **18.53** | **19.17** | **21.07** | **21.56** | **21.10** | **18.48** | **21.15** |

Totals may not add up because of rounding.
*Source: MoDNR 2021*

The economic impact analysis of Missouri State Parks is based on the methodology presented in *Missouri State Park Economics and Benefits: An Update Based on 2011 Visitation* (Case 2012), which is based on the 2002 *State Economic Impacts of Missouri State Park Visitors* report (Cole 2002). The methodology estimates the economic impact of visitors to state parks based on the annual number of visitors and the estimated visitor expenditures per day.

The dollar amount spent per visitor per day was estimated for four types of destinations, as shown in **Table 4-31**. The Case report compared the 2011 estimates of average visitor expenditures per day with the 2002 estimates and found the values were similar when adjusted for inflation. **Table 4-33** shows these estimates in 2020 dollars.

**Table 4-31. Average Expenditure per Visitor per Day in Missouri State Parks**

| Destination Type | $/Visitor/Day ($2011) | $/Visitor/Day ($2020) |
|---|---|---|
| State Park | $43.00 | $48.35 |
| State Historical Site | $58.00 | $65.22 |
| Museum | $58.00 | $65.22 |
| Old Home/Mansion | $61.00 | $68.59 |

*Source: D.J. Case and Associates 2012*

The total visitation at each state park was multiplied by the corresponding value for expenditure per visitor per day in 2020 dollars to estimate total visitor expenditures for each state park from 2011 to 2020. The estimated annual total expenditures are shown in **Table 4-32** in millions of 2020 dollars. The average annual expenditures in 2012 and 2014 suggest that expenditures in 2013 were down $45.8 million dollars. Similarly, the average annual expenditures in 2018 and 2020 suggest that expenditures in 2019 were down $128.8 million dollars. However, factors other than drought conditions may have impacted expenditures in these years.

**Table 4-32. Total Visitor Expenditures for All State Park Facilities, 2011 to 2020 (Million 2020 Dollars)**

| Year | Total Visitor Expenditures ($2020) |
|---|---|
| 2011 | $894 |
| 2012 | $908 |
| 2013 | $876 |
| 2014 | $936 |
| 2015 | $966 |
| 2016 | $1,063 |
| 2017 | $1,088 |
| 2018 | $1,055 |
| 2019 | $926 |
| 2020 | $1,055 |

The economic impact of visitor spending is typically characterized by the direct effects that spending has on the economy, and then by the total effect as money spent by visitors is re-spent, thus multiplying the impact of the direct expenditures. Direct effects result from the dollars that stay in Missouri directly from visitor spending (only a small portion of sales revenue goes to out-of-state vendors). The total effect of visitor spending is calculated as the visitor revenue re-spent within the state economy. Direct and total effects for 2020 were calculated proportionally to the 2011 data based on the annual total expenditures (Cole 2012).

The direct and total economic effects of visitor spending were calculated for each year from 2011 to 2020, as shown in **Table 4-33**. The overall economic impact of visitor expenditures to Missouri State Parks in 2020 was estimated at $1.384 billion in sales, $417 million in payroll and related income, and $167 million in federal, state, and local taxes. These visitor expenditures support over 19,700 jobs.

**Table 4-34** estimates the potential economic impacts of reducing the most recent 5-year average state park visitation and expenditures by 5, 10, 15, and 20 percent.

**Table 4-33. Total Visitor Expenditures in State Parks, 2011 to 2020 (Million 2020 Dollars)**

| All Visitors to Missouri State Parks | | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Visitor Expenditures | | $894 | $908 | $876 | $936 | $966 | $1,063 | $1,088 | $1,055 | $926 | $1,055 |
| Direct Effects | Sales | $807 | $820 | $791 | $845 | $872 | $959 | $982 | $952 | $836 | $952 |
| | Income | $216 | $219 | $212 | $226 | $233 | $257 | $263 | $255 | $224 | $255 |
| | Jobs | 10,624 | 11,016 | 10,779 | 11,681 | 11,989 | 13,299 | 13,846 | 13,685 | 12,189 | 14,095 |
| Total Effects | Sales | $1,173 | $1,192 | $1,150 | $1,228 | $1,268 | $1,394 | $1,428 | $1,385 | $1,215 | $1,384 |
| | Income | $353 | $359 | $346 | $370 | $382 | $420 | $430 | $417 | $366 | $417 |
| | Jobs | 14,851 | 15,398 | 15,066 | 16,328 | 16,759 | 18,590 | 19,354 | 19,129 | 17,038 | 19,702 |
| | Tax (federal, state, local) | $142 | $144 | $139 | $148 | $153 | $168 | $173 | $167 | $147 | $167 |

Totals may not add up because of rounding.

**Table 4-34. Potential Loss from Reduction in State Park Expenditures (Million 2020 Dollars)**

| Percent Reduction | | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| Total Visitor Expenditures | | $52 | $104 | $156 | $207 |
| Direct Effects | Sales | $47 | $94 | $140 | $187 |
| | Income | $13 | $25 | $38 | $50 |
| | Jobs | 671 | 1342 | 2013 | 2685 |
| Total Effects | Sales | $68 | $136 | $204 | $272 |
| | Income | $20 | $41 | $61 | $82 |
| | Jobs | 938 | 1876 | 2814 | 3752 |
| | Tax (federal, state, local) | $8 | $16 | $25 | $33 |

The relative potential for drought impacts to tourism by county is estimated from Missouri Division of Tourism annual reports (Missouri Division of Tourism 2021) and data obtained from the MoDNR Division of State Parks. The Missouri Division of Tourism data provides annual totals of tourism-related spending, employment, and state sales tax by county from 2011 to 2020. A 10-year average of tourism expenditures, employment, and state sales tax is estimated for each county and used to assign a value of 1 to 4 by quartile. The MoDNR Division of State Parks data on visitors and expenditures at state parks also covered 2011 to 2020, although not all counties contain a state park. The 10-year average of state park visitors and expenditures is used to assign a value of 1 to 4 by quartile, with a value of 1 assigned to counties without state parks.

The relative potential for drought impacts to tourism by county is shown in **Appendix B** and counties are ranked by the relative potential for impact. The relative potential for drought impacts to tourism is summarized by region in **Table 4-35**. The East Central Region has the greatest relative potential for drought impacts to tourism while the Northeast Region has the least relative potential for impacts.

**Table 4-35. Relative Drought Impact Potential for Tourism by Region**

| Region | Potential Impact Scores (1–4) for: | | | | | Average Tourism Potential Impact Score |
|---|---|---|---|---|---|---|
| | Tourism Expenditures | Tourism Employment | Tourism State Sales Tax | State Park Visitors | State Park Expenditures | |
| Central | 2.9 | 2.9 | 2.9 | 1.8 | 1.9 | 2.4 |
| East Central | 3.2 | 3.2 | 3.2 | 2.8 | 2.8 | 2.6 |
| North Central | 1.8 | 2.0 | 1.8 | 1.7 | 1.5 | 2.0 |
| Northeast | 1.6 | 1.7 | 1.6 | 1.4 | 1.4 | 1.7 |
| Northwest | 2.2 | 2.1 | 2.2 | 1.4 | 1.5 | 1.9 |
| South Central | 2.0 | 2.0 | 2.0 | 2.0 | 1.9 | 2.1 |
| Southeast | 3.1 | 2.9 | 3.1 | 1.3 | 1.3 | 2.5 |
| Southwest | 3.1 | 3.2 | 3.1 | 1.3 | 1.3 | 2.4 |
| West Central | 2.9 | 2.9 | 2.9 | 1.6 | 1.7 | 2.4 |

Note: Data is based on 10-year averages.
Lower scores reflect lower relative potential impact.

## 4.7 Other Indirect Impacts

This section has described the direct impacts of drought on agriculture, municipal and industrial water users, power generation, and tourism. The consequences of direct impacts can lead to numerous indirect impacts. The following are just some of many possible indirect impacts of drought:

- Loss of income for farms and associated agribusiness income loss
- Loss of landscape, foliage, and urban forests
- Wildfires resulting in loss of forest, pastures, grasslands, and property
- Higher food costs
- Impacts on the housing market
- Impacts on public health because of heat stress, water contamination, dust and respiratory ailments, and mental health
- Reduced barge traffic on waterways and cost of dredging
- Foundation damage, land subsidence, and water distribution line breaks from shifting soils
- Cost of deepening wells for agricultural irrigation, municipal water supply, or industrial use
- Cost of emergency interconnections or other sources of water supply
- Concentrations of pollutants and sediments in waterways, and the resulting higher cost to treat the water for public supply purposes
- Impacts to aquatic habitat and species from decreased dissolved oxygen levels
- Increased color and odor from microbial growth in water sources, and the resulting higher cost to treat the water for public supply purposes

## 4.8 Summary

Potential drought impacts to each region are presented and summarized for the agriculture, municipal water supply, industry, power production, and tourism and recreation sectors. Regions of the state are ranked by potential drought impacts within each sector, except for the power production sector since the impact of a reduction in power generation is distributed across a larger network through the power grid, which spans multiple regions and even states. The potential impact scores for each sector are shown by region in **Table 4-36**, and a total potential impact score for each region is assigned by averaging the impact score for each sector. While it is recognized that the potential impacts to one sector may be significantly higher than another sector, no weighting is applied to reflect the potential economic value of one sector over another in Table 4-36. Each sector is weighted equally, when combining the potential impact scores to arrive at an average impact score. Table 4-37 compares the rankings of the regions for each of the sectors along with the ranking from the overall average.

The Southwest and West Central regions have the highest total potential impact scores, followed by the Southeast, East Central, and Central regions reflecting higher potential for drought impacts. The South Central, North Central, Northwest, and Northeast regions have less potential to incur drought damages, when considering all sectors combined. A similar table by county is provided in **Appendix B**, along with a table of the counties ranked by the total score.

As noted, the relative rankings shown in **Table 4-37** give equal weight to each of the four economic sectors. A rank of one (1) indicates the least relative potential for drought damages while a rank of nine (9) indicates the most relative potential for damages.

**Table 4-36. Relative Drought Impact Potential Score by Region and Sector**

| Region | Potential Impact Scores (1–4) | | | | |
|---|---|---|---|---|---|
| | Agriculture | Municipal Water Supply | Industry | Tourism | Average |
| Central | 2.9 | 2.7 | 2.1 | 2.4 | 2.5 |
| East Central | 2.1 | 2.9 | 2.5 | 2.6 | 2.5 |
| North Central | 2.6 | 2.0 | 1.7 | 2.0 | 2.1 |
| Northeast | 3.0 | 1.9 | 2.1 | 1.7 | 2.2 |
| Northwest | 2.2 | 2.4 | 1.8 | 1.9 | 2.1 |
| South Central | 1.9 | 1.8 | 2.0 | 2.1 | 2.0 |
| Southeast | 2.1 | 3.3 | 2.2 | 2.5 | 2.5 |
| Southwest | 3.1 | 3.0 | 2.5 | 2.4 | 2.7 |
| West Central | 3.0 | 3.1 | 1.9 | 2.4 | 2.6 |

Note: Lower scores reflect lower relative potential impact.

**Table 4-37. Rankings of Relative Drought Impact Potential by Region and Sector**

| Region | Agriculture | Municipal Water Supply | Industry | Tourism | Rank of Average |
|---|---|---|---|---|---|
| Central | 6 | 5 | 5 | 5 | 5 |
| East Central | 2 | 6 | 9 | 9 | 6 |
| North Central | 5 | 3 | 1 | 3 | 2 |
| Northeast | 8 | 2 | 6 | 1 | 4 |
| Northwest | 4 | 4 | 2 | 2 | 3 |
| South Central | 1 | 1 | 4 | 4 | 1 |
| Southeast | 3 | 9 | 7 | 8 | 7 |
| Southwest | 9 | 7 | 8 | 7 | 9 |
| West Central | 7 | 8 | 3 | 6 | 8 |

Rank of 1 indicates the region with the least potential for drought damages.

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# Section 5 Assessment of Drought Vulnerability

## 5.1 Introduction

For the purposes of this plan, drought vulnerability is defined as the combination of four elements of drought: likelihood, susceptibility, impact, and resilience. This section discusses drought likelihood and susceptibility by region and combines the results from the assessments of resilience in Section 3 and impacts in Section 4 to characterize each region's overall vulnerability to drought. By identifying and understanding regional differences in each of these elements, mitigation and response strategies can be appropriately considered and selected to address the elements that most contribute to drought vulnerability. The strategies to prepare for and respond to drought are further developed in Section 7, Drought Mitigation and Response, and Section 8, Drought Mitigation Actions.

Analysis of historical drought-related data indicates that some regions of Missouri are more likely to experience drought than others. These differences in drought frequency and severity are driven in part by the historical trend of increasing precipitation from the northwest, where the most recent 30-year average annual precipitation is 34 inches, to the southeast, where the 30-year annual average is 50 inches. Susceptibility to drought is assessed by identifying the sources and amount of water available for use in a particular region, current and future demands, and the potential for gaps in supply. Drought likelihood and susceptibility are discussed on the following pages, regional differences are identified, and the nine crop reporting districts are ranked relative to each other. At the end of this section, vulnerability ratings for each crop reporting district are assigned.

### Overview of Section 2 5 Assessment of Drought Vulnerability

This section discusses the likelihood, susceptibility, and overall vulnerability to drought by region within Missouri. Subsections are organized as follows:

- Section 5.2 Drought Likelihood – identifies the regions of Missouri that are more likely to experience drought, based on analysis of historical drought frequency and severity and projected trends in future precipitation and temperature.
- Section 5.3 Drought Susceptibility – characterizes regional susceptibility to drought through analysis and modeling by examining the sources of water, water availability, and demands on water supplies.
- Section 5.4 Regional Vulnerability – presents an assessment of overall vulnerability to drought by combining the elements of likelihood, susceptibility, impact, and resilience for each region.

## 5.2 Drought Likelihood

An assessment of drought likelihood attempts to answer the question: *What is the probability of drought of certain intensity and severity occurring in a region*? To determine drought likelihood, both historical drought records and future climate projections were evaluated. The likelihood of drought in Missouri has historically varied by region because of differences in precipitation and, to a lesser extent, variations in temperature, which influence evaporation rates. Looking to the future, global climate models (GCMs) generally project a trend of increasing temperatures. With higher temperatures, increased evaporation from surface water and soils and higher rates of water uptake by plants (transpiration) might be expected, which may increase the intensity of droughts. While trends in actual pan evaporation data from Missouri over the last half century do not suggest evaporation rates are increasing with increasing temperatures (perhaps due to factors such

as changes in solar radiation intensity or increasing level of pollutants in the air), some increase in seasonal evaporation rates continues to be a potential outcome, as temperatures continue to increase.

The number of heavy rainfall events is also projected to increase but total rainfall volume is not projected to change significantly, which translates to an increasing number of dry days between precipitation events. Higher temperatures, increased evapotranspiration rates, and an increased number of consecutive dry days increases the likelihood of drought, especially agricultural drought (State Emergency Management Agency [SEMA] 2018).

### 5.2.1 Historical Drought Frequency and Severity

The *Missouri State Hazard Mitigation Plan*, published by SEMA in 2018, contains information on the probability of drought by climate division based on Palmer Drought Severity Index (PDSI) data from 1895 to 2016. The six climate divisions developed by the National Oceanic and Atmospheric Administration (NOAA) in the 1950s are shown in **Figure 5-1**. While the projected PDSI values presented in this section are based on those developed by climate division, the results have been translated to the nine crop reporting districts to maintain consistency with the Drought Mitigation and Response Plan.

Based on PDSI rating, the Northwest Prairie and Northeast Prairie climate divisions have historically been in severe or extreme drought more often than the rest of the state. However, analysis of historical PDSI can obscure some of the variation that occurs across Missouri because of data only being available at the climate-division level. Therefore, additional analysis was performed using the Drought Severity Coverage Index by county for the 30-year period from 1991 to 2020. The county-level data were aggregated by crop reporting district. As shown in **Figure 5-2**, the Northwest and West Central districts have historically spent the most amount of time in severe drought or worse conditions, followed by the North Central, Northeast, and Southwest districts.

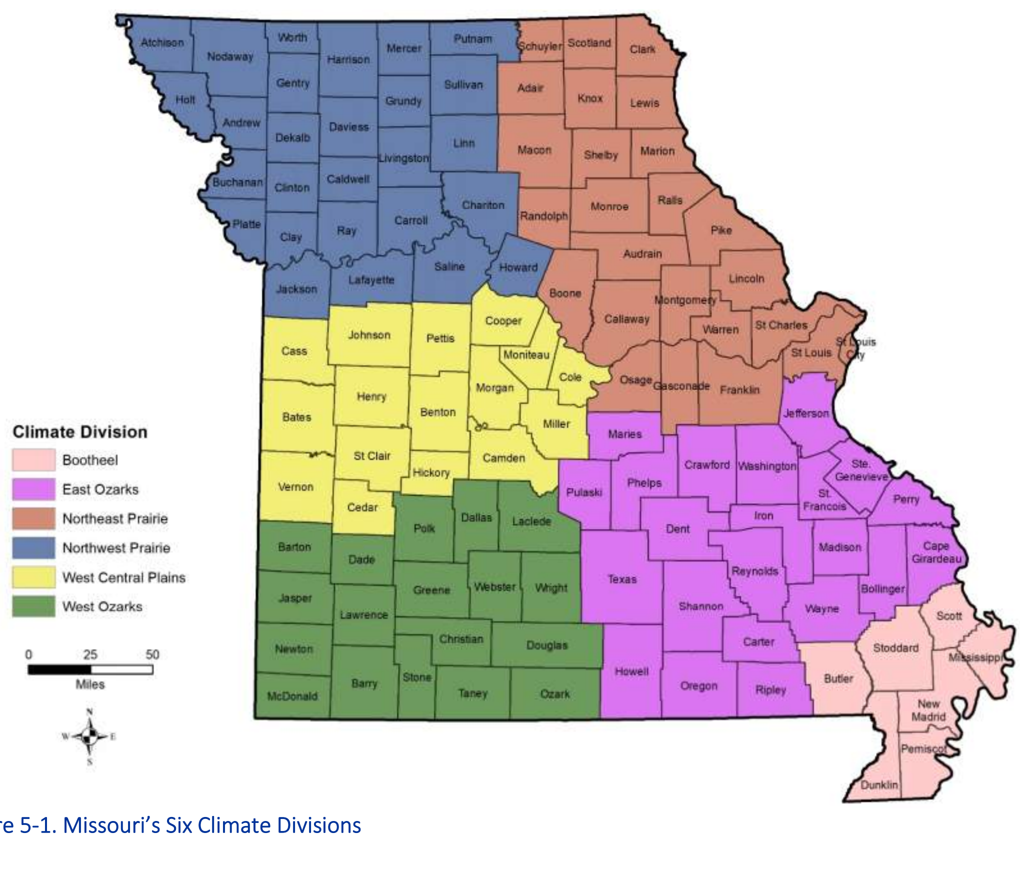



Figure 5-1. Missouri's Six Climate Divisions

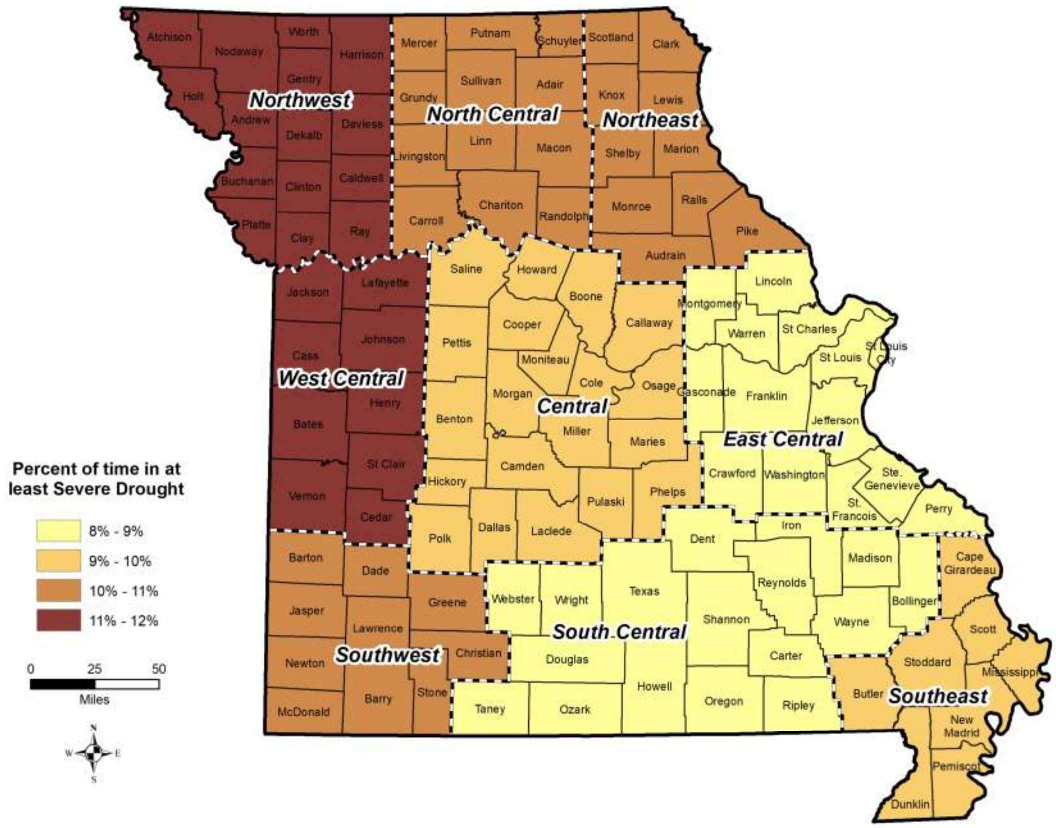



Figure 5-2. Drought Probability Based on the Drought Severity Coverage Index from 1991 to 2020 by Crop Reporting District

### 5.2.2 Projected Drought Likelihood

Analysis of projected PDSI values by climate division was performed to quantify the potential influence of changing climate on drought likelihood. GCM projections representing changes in temperature and precipitation through the end of the century are available for any location in the contiguous United States. By themselves, these projections have limited utility in directly informing drought planning. Therefore, for this analysis, the climate projections are translated into a direct indicator of drought severity. The projections were also assessed for statistically significant time trends to discern true nonstationarity from random variability. PDSI is only one indicator of drought, which specifically focuses on soil moisture levels. PDSI does not, for example, provide a meaningful characterization of surface water availability, including reservoir and stream levels.

Analyses were performed for each of the six climate divisions in Missouri. GCM projections were downscaled to locations central to each climate division. Only projections from the latest World Climate Research Programme's Coupled Model Intercomparison Project Release 5 were used in this analysis, specifically, monthly projections of air temperature and precipitation through the year 2070. A total of 112 GCM projections were used, spanning 37 different climate models and a range of standard assumptions about future greenhouse gas emissions. These projections represent the best available science on future climate conditions.

PDSI values were calculated for each timestep in the monthly projections to assess drought conditions reflected by the climate data sets. A customized version of NOAA's National Climatic Data Center PDSI calculator was used to calculate PDSI values for each of the GCM projection traces for both the 21st century projection period (2000 to 2070) and the historical hindcast period (1950 to 1999).

The ensemble of GCMs have a projected decrease in annual average PDSI through 2070 for all climate divisions. Drought severity levels, as related to soil moisture, are projected to deteriorate on average from a condition of primarily incipient dry to a multidecadal condition of mild to moderate drought by the end of the century. This is shown in **Figure 5-3**, which depicts the trend line of average annual PDSI values for each climate division. Descriptions of the drought categories associated with each PDSI value are provided for reference. While all climate divisions are projected to have a decrease in annual average PDSI, the Northwest Prairie climate division is projected to have the lowest average annual PDSI and the Bootheel is projected to have the highest by 2070. Additional discussion of the methodology and results of the future PDSI analysis is included in **Appendix C**.

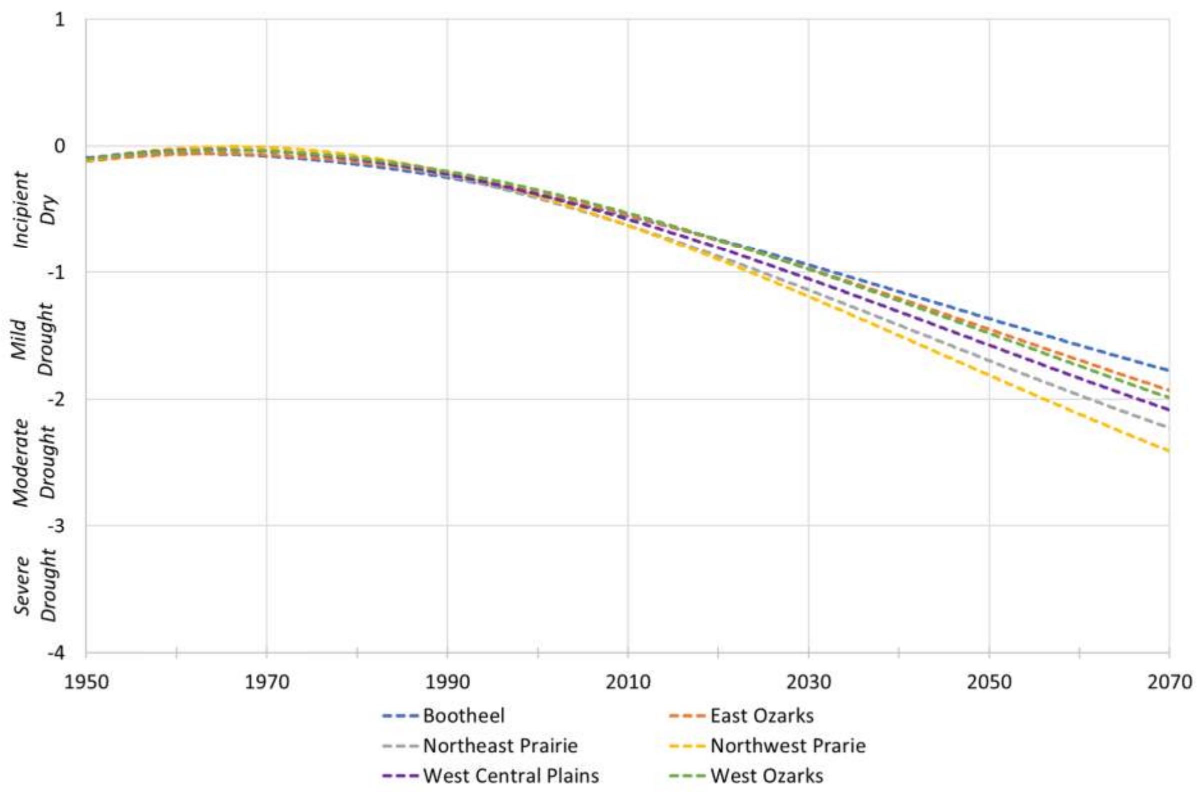



Figure 5-3. Historical (Modeled) and Projected Average Annual PDSI Trend Lines by Climate Division

The projections suggest a likely future decrease in average soil moisture levels throughout the state owing to warming temperatures. Decreasing soil moisture projections suggest an increasing demand for irrigation water in the future. Results may also imply a gradual shift to alternative crop types or agricultural practices, as necessitated by water availability.

PDSI is only one measure of drought and reflects soil moisture levels. Other measures of drought, including river and stream flows and lake levels, are not reflected in PDSI. With potentially increasing precipitation in the future, as projected by some of the climate models, changes in surface water availability may occur in the opposite direction of the projected PDSI changes. The difference between the two is attributable to differences in sensitivity to air temperature changes.

Results for projected PDSI values by climate division were converted to crop reporting districts by calculating the relative percent of counties in each climate division that fall within the crop reporting districts. The projected PDSI values by crop reporting district, as shown in **Table 5-1**, exhibit the same

trends as projected PDSI by climate division but allow for the ranking of likelihood assessment to be combined with other aspects of the Drought Mitigation and Response Plan. The Northwest crop reporting district is projected to experience the most severe drought conditions by through the 2060s. The Southeast crop reporting district is projected to be the least impacted region of the state compared to other crop reporting districts, although the soil moisture levels are still projected to decrease somewhat significantly.

**Table 5-1. Projected Average PDSI by Decade and Crop Reporting District**

| Crop Reporting District | 2020 | 2030 | 2040 | 2050 | 2060 |
|---|---|---|---|---|---|
| Central | -0.97 | -1.32 | -1.32 | -1.64 | -1.87 |
| East Central | -0.98 | -1.31 | -1.35 | -1.65 | -1.86 |
| North Central | -1.07 | -1.51 | -1.49 | -1.83 | -2.12 |
| Northeast | -1.05 | -1.43 | -1.42 | -1.76 | -2.00 |
| Northwest | -1.07 | -1.56 | -1.52 | -1.86 | -2.18 |
| South Central | -0.89 | -1.15 | -1.25 | -1.52 | -1.70 |
| Southeast | -0.86 | -1.12 | -1.17 | -1.42 | -1.56 |
| Southwest | -0.88 | -1.19 | -1.25 | -1.55 | -1.72 |
| West Central | -1.01 | -1.38 | -1.35 | -1.68 | -1.94 |

| *Incipient Dry (0 to -1)* | *Mild Drought (-1 to -2)* | *Moderate Drought (-2 to -3)* | *Severe Drought (-3 to -4)* | *Extreme Drought (below -4)* |
|---|---|---|---|---|

Based on the results shown in **Table 5-1**, rankings of future likelihood were established for each crop reporting district. The future rankings were combined with the historical rankings based on the historical likelihood of drought to determine an overall likelihood ranking by crop reporting district, as shown in **Table 5-2**. Equal weight was given to the rankings of historical and future likelihood when developing the overall relative ranking by district. While the Southeast district is ranked as having the lowest likelihood of drought and the Northwest district is ranked as having the highest relative to other districts, the variation in likelihood between districts is relatively small. Drought may occur in all crop reporting districts of the state.

**Table 5-2. Drought Likelihood Ranking by Crop Reporting District**

| Crop Reporting District | Historical Ranking | Future Ranking | Aggregated Likelihood Ranking |
|---|---|---|---|
| Central | 4 | 5 | 4 |
| East Central | 2 | 4 | 3 |
| North Central | 7 | 8 | 8 |
| Northeast | 5 | 7 | 6 |
| Northwest | 9 | 9 | 9 |
| South Central | 1 | 2 | 1 |
| Southeast | 4 | 1 | 2 |
| Southwest | 6 | 3 | 4 |
| West Central | 8 | 6 | 7 |

Note: A ranking of 1 equals the lowest relative drought likelihood and a ranking of 9 equals the highest.

## 5.3 Drought Susceptibility

Regional susceptibility to drought was originally assessed by region in the *2002 Missouri Drought Plan* (Missouri Department of Natural Resources [MoDNR] 2002). **Figure 5-4** depicts the regions, which were assigned susceptibility ratings of slight, moderate, and high based on availability and access to suitable quality groundwater and surface water resources. Region A, which is underlain by alluvial deposits, was assigned a slight susceptibility rating; surface and groundwater resources were deemed to be generally adequate for domestic, municipal, and agricultural water needs. Region B was assigned a moderate susceptibility rating; it was determined to have adequate water to meet domestic and municipal water needs but has greater difficulty in obtaining groundwater, especially for agricultural purposes. Region C was assigned a high susceptibility rating; surface water resources are known to be inadequate during extended drought and groundwater resources are of poor quality outside of limited areas where shallow groundwater is available in glacial deposits. The plan also identified additional factors that should be considered when determining susceptibility. These include:

- Historical drought occurrence in an area/region
- Actual annual and seasonal rainfall amounts
- Current and projected water demands and uses within an area
- Sources of water available for use
- Water reserves and accessibility to additional water supplies
- Current populations and projected population trends that are linked to water use amounts

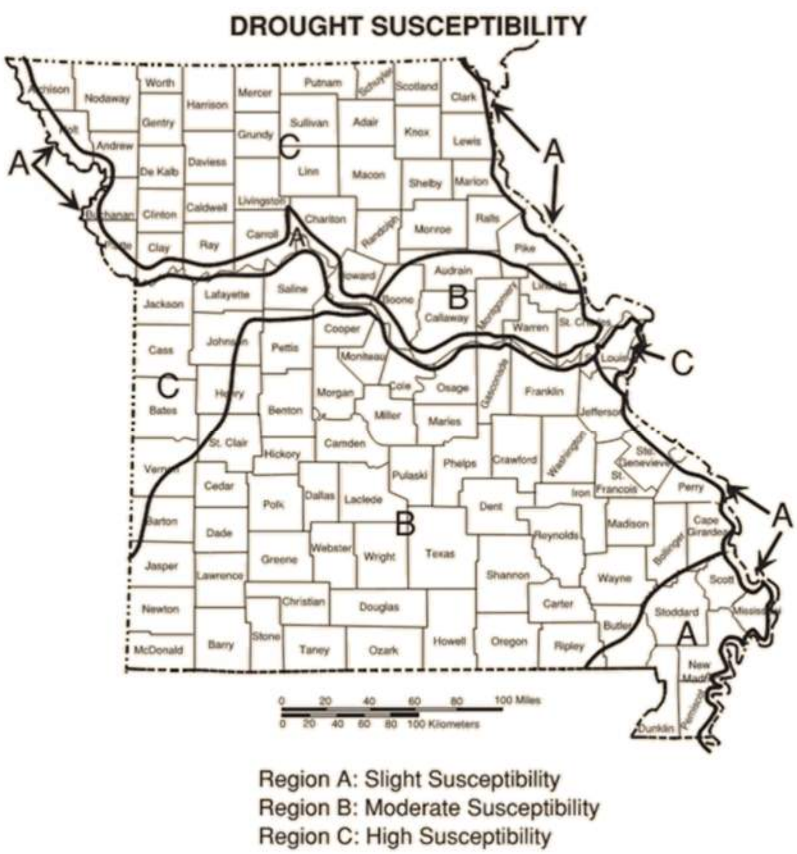



Figure 5-4. Drought Susceptibility Map from the 2002 Missouri Drought Plan

This Drought Mitigation and Response Plan update builds on the original assessment of susceptibility and considers several of the additional factors listed on the previous page, including current and projected population and water demands, the amount of water available for use, and the potential for future water stress during drought under several different planning scenarios. These factors were evaluated as part of the 2020 Missouri Water Resources Plan (MoDNR 2020). Current and future population and water use were identified by county and at the hydrologic unit code 4 (subregional) level. Current and projected future gaps in supply were identified using detailed water budgets that assessed the level of potential water stress under average annual hydrologic conditions, drought conditions, and drought of record conditions.

Additionally, the groundwater flow model of the Ozark Plateaus aquifer system developed by the U.S. Geological Survey (USGS) was used to further evaluate the susceptibility of groundwater resources to extended drought in southern Missouri. These evaluations are presented in the following subsections.

### 5.3.1 Current and Projected Population and Water Demands

The East Central, West Central, and Central crop reporting districts, which include three of the four largest cities in the state (St. Louis, Kansas City, and Columbia), have the highest current (2020) and projected 2060 populations, as shown in **Table 5-3**. Together, they account for 65 percent of the population of the state; however, that percentage is expected to drop slightly to 63 percent by 2060. The Northwest (at 43 percent), Southwest (at 21 percent), and Central (at 28 percent) districts are expected to have the highest percent change in population from 2020 to 2060. One of the largest-growth counties in the Northwest district is Clay County, which includes the portion of Kansas City north of the Missouri River.

**Table 5-3. Estimated 2020 and Projected 2060 Population, Groundwater Demands, and Surface Water Demands by Crop Reporting District (MoDNR 2020)**

| Crop Reporting District | Population | | | Groundwater Demand (MGD) | | | Surface Water Demand (MGD) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2060 | Percent Change | 2020 | 2060 | Percent Change | 2020 | 2060 | Percent Change |
| Central | 757,029 | 969,700 | 28% | 88 | 117 | 32% | 44 | 51 | 17% |
| East Central | 2,355,848 | 2,686,612 | 14% | 73 | 98 | 34% | 378 | 402 | 6% |
| North Central | 140,180 | 132,792 | -5% | 12 | 12 | 2% | 31 | 36 | 18% |
| Northeast | 124,598 | 118,802 | -5% | 24 | 26 | 11% | 20 | 22 | 10% |
| Northwest | 592,983 | 846,427 | 43% | 87 | 108 | 24% | 56 | 83 | 48% |
| South Central | 318,995 | 387,294 | 21% | 204 | 236 | 16% | 30 | 39 | 31% |
| Southeast | 275,492 | 292,490 | 6% | 1,877 | 2,134 | 14% | 16 | 20 | 23% |
| Southwest | 730,029 | 1,002,911 | 37% | 104 | 132 | 28% | 53 | 71 | 34% |
| West Central | 978,689 | 1,047,876 | 7% | 81 | 87 | 7% | 81 | 90 | 11% |

MGD = million gallons per day
Note: All demands listed are consumptive demands.

Just over 73 percent of statewide groundwater demands are in the Southeast crop reporting district, where most of the water used for consumptive purposes is for crop irrigation. Groundwater demands in the Southeast district are also expected to increase the most (for total amount) by 2060, an additional 257 MGD. The East Central, Central, and Southwest districts are expected to have the highest percent change in groundwater demand from 2020 to 2060, ranging from 28 to 34 percent. Surface water demands are highest in the East Central district and account for approximately 50 percent of the statewide total demand from surface water. Surface water demands are expected to increase the most (for total amount) by 2060 in the Northwest district, an additional 27 MGD. The Northwest, Southwest, and South Central districts are

expected to have the highest percent change in surface water demand from 2020 to 2060, ranging from 31 to 48 percent (MoDNR 2020).

Seventy-eight percent of consumptive demands statewide are supplied by groundwater with the remaining 22 percent supplied by surface water (MoDNR 2020). Groundwater demands are heavily driven by agriculture irrigation and concentrated in the alluvial aquifer of the Southeast crop report district, which account for 67 percent of total consumptive demands. Lower Ozark Aquifer demands represent another 8 percent of total consumptive water demands.

Statewide, agriculture irrigation comprises the largest portion of consumptive water demands at 65 percent on average, as shown in **Figure 5-5**. Major water systems make up 25 percent of average annual consumptive demands. The remaining sectors combined represent 10 percent of annual withdrawals. Overall statewide consumptive demands are estimated to increase by 18 percent or 582 MGD by 2060, as shown in **Figure 5-6**. Statewide demands are estimated to total over 3,780 MGD by 2060. Agriculture irrigation and major water systems will remain the largest consumers of water in 2060 (MoDNR 2020).

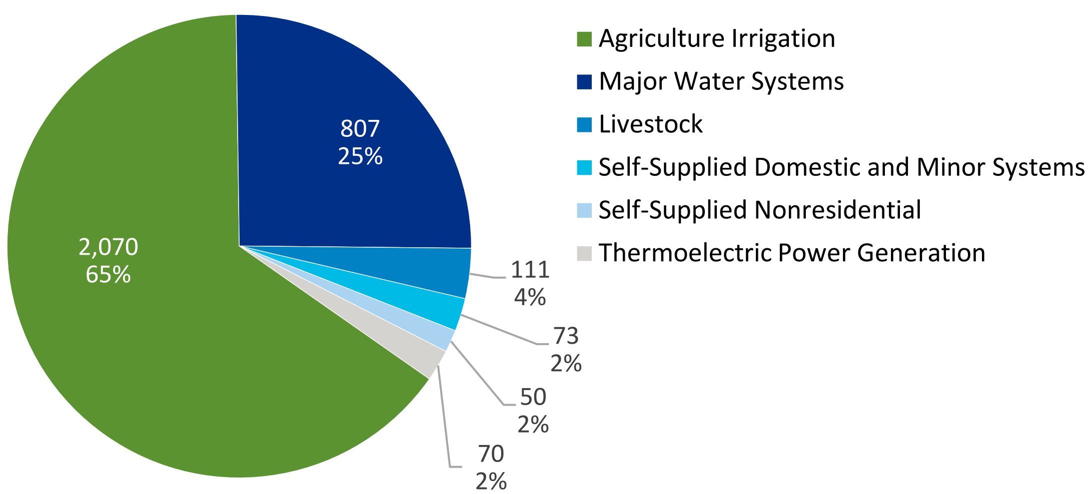



Figure 5-5. Current Consumptive Demands by Sector in MGD (MoDNR 2020)

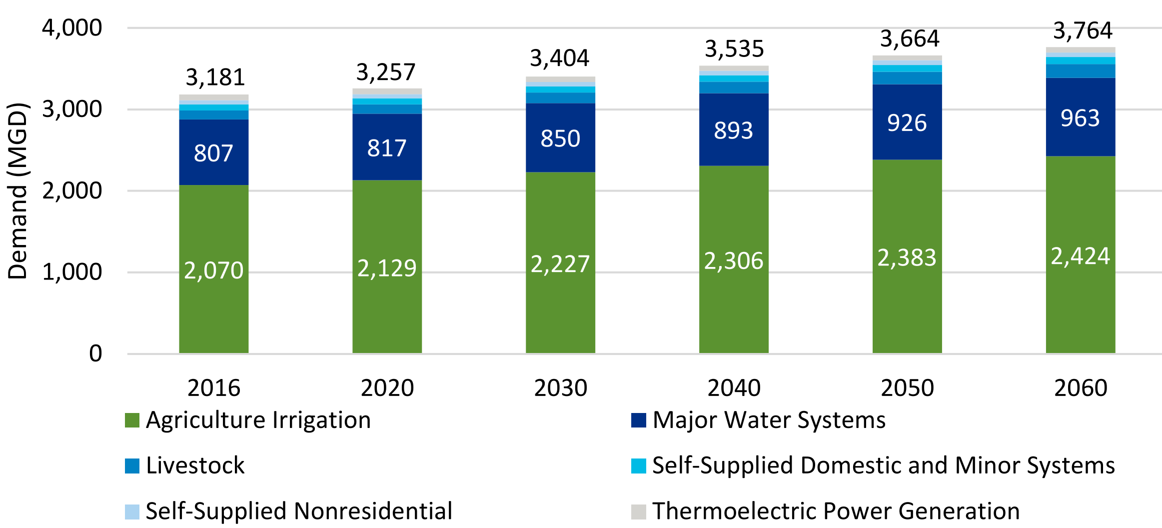



Figure 5-6. Consumptive Demand Forecast by Sector to 2060 (MoDNR 2020)

### 5.3.2 Water Budgets

The subregional water budgets developed as part of the 2020 Missouri Water Resources Plan generally demonstrate that Missouri has an abundant supply of water for consumptive and nonconsumptive uses on an average annual basis. Surface water withdrawals, both consumptive and nonconsumptive, are typically only a small fraction of total streamflow in each subregion. However, this does not obviate the need to continue to maintain flows on the state's waterways for nonconsumptive uses, such as power generation and navigation. In addition, minimum flows must be maintained even when demands are being met to preserve water temperature, water quality, ecological diversity, and the viability of existing water supply intakes, all of which are put at risk if surface water supply decreases in the future.

Similarly, the water budgets show that projected groundwater withdrawals in most subregions are less than 20 percent of average annual recharge from precipitation and other aquifers and only a very small fraction of potable groundwater available in storage. In the few subregions where groundwater withdrawals are greater than 20 percent of average annual recharge from precipitation, much of the pumping is from alluvial aquifers, which are hydraulically connected to major rivers and other aquifers.

Water supply availability in the state's nine subregions, as characterized by the water budgets presented in the 2020 Missouri Water Resources Plan, is summarized below. The subregions are shown in dark blue on each map and are overlain by the crop reporting district boundaries in white.

- **Upper Mississippi-Salt** – This subregion generally coincides with the Northeast crop reporting district. Surface water withdrawals, excluding withdrawals from the Mississippi River, approach or exceed median dry year flows in 4 months of the dry year and in 3 months of the drought of record year. The results suggest a potential for surface water gaps in areas of the subregion that do not have access to the Mississippi River and emphasize the importance of reservoir storage, interconnections with other systems, conjunctive use of groundwater, or other means to bridge these potential supply gaps. The subregion includes eight water supply reservoirs that help mitigate against the potential surface water supply gaps identified in the monthly streamflow analysis. Groundwater availability, especially in the Mississippi River Alluvial Aquifer and Cambrian-Ordovician Aquifer, is enough to meet current and future needs through 2060.

- **Upper Mississippi-Kaskaskia-Meramec** – This subregion generally coincides with the lower half of the East Central crop reporting district but also includes small portions of the Central, South Central, and Southeast districts. Surface water users in the western part of the subregion withdraw from tributaries to the Mississippi River that provide ample supply even during dry years and the drought of record year. Groundwater availability, especially in the Mississippi River Alluvial Aquifer and Ozark Aquifer, is enough to meet current and future needs through 2060. No water stress or water supply gaps were identified at the subregion level under average annual hydrologic conditions.

- **Lower Mississippi-St. Francis** – This subregion generally coincides with the lower half of the Southeast crop reporting district but also includes small portions of the East Central and South Central districts. The subregion relies heavily on groundwater. Although current groundwater withdrawals exceed average annual recharge from precipitation, observation wells in the subregion have shown no long-term declines. Recharge sources other than precipitation, namely the Mississippi, St. Francis, and Black rivers and the Ozark Aquifer in the northwest, likely contribute significant amounts of flow into the Southeast Lowlands Alluvial

Aquifer. As a result, groundwater availability is enough to meet current and projected needs without imposing stress or resulting in supply gaps. Potable groundwater stored in the aquifers is enough to meet groundwater demands even during prolonged droughts, when recharge from precipitation is much lower.

- **Missouri-Nishnabotna** – This subregion generally coincides with the western half of the Northwest crop reporting district. The Missouri River and Missouri River Alluvial Aquifer are the major sources of water in this subregion. Roughly 80 percent of surface water withdrawals and 95 percent of groundwater withdrawals are from the Missouri River and its alluvial aquifer, respectively. Water users in the eastern part of the subregion must rely on tributaries to the Missouri River. The combined withdrawals from tributaries to the Missouri River approach or exceed median dry year streamflow in 3 months and drought of record year streamflow in 5 months of the year. There is the potential for surface water gaps in areas of the subregion that do not have access to the Missouri River, or its alluvial aquifer.

- **Chariton-Grand** – This subregion generally coincides with the North Central crop reporting district but includes the eastern portion of the Northwest district. Not accounting for thermoelectric withdrawals, total water use is relatively low in this subregion and reflects the relatively low population density. Water users rely primarily on surface water resources since good-quality and quantity groundwater is limited to portions of the Glacial Drift Aquifer, in limited locations throughout the subregion, and Missouri River Alluvial Aquifer in the south. Surface water withdrawals exceed drought of record year flows in 1 month of the year, suggesting the potential for a surface water gap. The subregion includes 32 water supply reservoirs with a total storage of 96,707 acre-feet. Reservoirs are an important component of the subregion's overall water supply system because of limited availability of sufficient potable groundwater sources, lower average rainfall, and history of drought.

- **Gasconade-Osage** – This subregion coincides with nearly all the West Central crop reporting district, approximately half of the Central district, and small portions of three other districts. Although the monthly streamflow analysis at the subregion level does not indicate the potential for stress or a surface water gap under current or future conditions, water stress and the potential for water shortages have previously been identified in more localized areas of southwest Missouri, including the western portion of the Gasconade-Osage subregion. The Ozark and St. Francois aquifers are estimated to store a combined 138 trillion gallons of potable groundwater in the subregion. However, groundwater becomes mineralized in the western portion of the subregion. Even though groundwater recharge greatly exceeds withdrawals and large amounts of potable groundwater are available in storage, localized stress may still occur because of over pumping or poor groundwater quality, especially in the western counties of the subregion on the saline side of the freshwater-saline transition zone.

- **Lower Missouri** – This subregion primarily coincides with the upper half of the Central crop reporting district but also includes small portions of the West Central, Northwest, North Central, and East Central districts. The Missouri River and Missouri River Alluvial Aquifer are the major sources of water in this subregion. The Ozark Aquifer (south of the Missouri River) and Cambrian-Ordovician Aquifer (north of the Missouri River) are also significant groundwater sources. Although flow in the Missouri River exceeds total surface water withdrawals, surface water users in the northern and southern parts of the subregion must rely on tributaries to the Missouri River. Withdrawals from the tributaries exceed median dry year flows

in 5 months of the dry year and in 8 months of the drought of record year. The results suggest the potential for surface water gaps in areas of the subregion that do not have access to the Missouri River, or its alluvial aquifer, for supply, and emphasize the importance of reservoir storage, adequate and dependable Missouri River flows, interconnections with other systems, and conjunctive use of groundwater together with other means to bridge these potential supply gaps.

- **Upper White** – This subregion coincides with most of the South Central crop reporting district and includes small portions of the Southwest and Southeast districts. The subregion has abundant surface and groundwater resources. Surface water withdrawals remain an order of magnitude below median dry year flows in any month. The relatively consistent streamflow even during dry periods is in part because of the thousands of springs and outlet points in the subregion, which provide consistent base flow to streams. Although results of the monthly streamflow analysis at the subregion level do not point to the potential for stress or a surface water gap under current or future conditions, the potential for shortages is a concern in growing areas such as Springfield, which sits on the drainage divide between the Upper White and Gasconade-Osage subregions. Within the subregion, the Ozark and St. Francois aquifers are estimated to store a combined 105 trillion gallons of potable groundwater.

- **Neosho-Verdigris** – This subregion lies within the western portion of the Southwest crop reporting district. Comparisons of surface water withdrawals to streamflow show that withdrawals approach but do not exceed median dry year and drought of record year streamflow in 2 months, indicating the potential for water stress. Although the groundwater budget suggests that total withdrawals are less than average annual recharge to the water table, a gradual long-term lowering of water levels has been observed in localized portions of the Ozark Aquifer in southwestern Missouri. The declining water levels indicate that withdrawals from the Ozark Aquifer in this localized area have exceeded long-term recharge to the aquifer and continue to reduce the amount of groundwater in storage. Similar localized declines, although not as severe, have been observed in observation wells in other parts of the subregion and suggest that future groundwater withdrawals in these areas may not be sustainable at current levels given the continual decline in storage. Extended drought conditions may exacerbate the declines.

### 5.3.3 Susceptibility to Drought Under Future Planning Scenarios

#### 5.3.3.1 Surface Water Resources

The 2020 Missouri Water Resources Plan evaluated four planning scenarios to determine Missouri's ability to meet water resource needs under drought conditions. The monthly water budgets were revised to reflect changes to demands (as influenced by potential economic and climate factors) and supply (as influenced by potential climate factors). In all subregions and in select subbasins, the revised 2060 monthly demands were compared to the revised supply totals to identify potential water stress or gaps arising under each scenario. The four scenarios are described below.

- **Business-as-Usual (or baseline) scenario.** The baseline scenario used the current projections for population growth and municipal and industrial (M&I) demands, and historical long-term averages for temperature and precipitation. Medium levels of water demand for irrigation and agricultural processing were assumed.

- **Strong Economy/High Water Stress.** This scenario assumed that population growth through 2060 is approximately 22 percent higher than the baseline projected population growth shown in **Table 5-3**. Consistent with a strong economy, high M&I and agriculture demands were assumed relative to the other scenarios. Demands for agricultural processing were set at a medium-high level

relative to the other scenarios. Climate projections categorized by hot, dry temperatures and lower precipitation were used.

- **Substantial Agricultural Expansion.** This scenario primarily evaluated the implications of strong growth in the agricultural processing sector. Like the baseline, this scenario used current projections for population growth and M&I demands. Relative to the other scenarios, a medium level of water demand for irrigation was assumed; however, high demands for agricultural processing were included. Climate projections categorized by warmer temperatures and greater precipitation were used.

- **Weak Economy/Low Water Stress.** This scenario assumed slightly lower population growth, resulting in 8 percent lower 2060 population estimates compared to the baseline 2060 population estimates shown in **Table 5-3**. This corresponds to a 10 percent lower urban population growth and a baseline (no change) in rural population. Consistent with the slower population growth and a weak economy, lower M&I demands were assumed relative to the other scenarios. A medium level of water demand for irrigation and agricultural processing was assumed. Climate projections categorized by warmer temperatures and greater precipitation were used.

In all subregions, projected 2060 surface water demands were compared to surface water supplies (before adjustment by the specific scenario drivers) as they existed during the drought of record year for each subregion. The drought of record occurred during 1954 or 1956, depending on the subregion.

The method used to characterize, categorize, and graphically depict the level of potential surface water supply stress under each scenario is shown in **Table 5-4**. When projected 2060 demands in a subregion or subbasin were less than 50 percent of available supply for every month of the year, No Stress was assigned. Two categories of increasing levels of potential water supply stress were defined: Low Potential Stress and Higher Potential Stress. If demand was greater than 50 percent but less than 100 percent of the supply for 1 month or more, Low Potential Stress was assigned. If demand was greater than supply for 1 month or more, Higher Potential Stress was assigned. The categorization of relative potential surface water supply stress helped to compare the impacts between different scenarios and identify options and strategies to mitigate or eliminate impacts. For this analysis, major river (i.e., the Missouri and Mississippi rivers) demands and supply were not included in the evaluation of determining potential surface water supply stress.

**Table 5-4. Identifying Potential Surface Water Supply Stress for Surface Water (MoDNR 2020)**

| Condition | Analysis | Result | Potential Water Supply Stress | Key for Figures |
|---|---|---|---|---|
| Average and Drought of Record | Monthly | Demand <50% of supply for entire year | No Stress | |
| | | Demand >50% and <100% of supply for 1 month or more | Low Potential Stress | |
| | | Demand > supply for 1 month or more | Higher Potential Stress | |

< = less than
> = greater than

A summary of the subregion surface water supply stress for each scenario in a drought condition is shown in **Table 5-5**. The Business-as-Usual, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress scenarios all have the same number of subregions showing similar potential water stress with one exception for the Strong Economy/High Water Stress scenario, as shown the table.

**Table 5-5. Subregion Surface Water Supply Stress Summary (Drought Conditions) (MoDNR 2020)**

| Potential Water Supply Stress Category | | Number of Subregions in Each Category | | | |
|---|---|---|---|---|---|
| | | Scenario 1 – Business-as-Usual | Scenario 2 – Strong Economy/High Water Stress | Scenario 3 – Substantial Agricultural Expansion | Scenario 4 – Weak Economy/Low Water Stress |
| | Demand <50% of supply for entire year | 0 | 1 | 0 | 0 |
| | Demand >50% and <100% of supply for 1 month or more | 1 | 1 | 1 | 1 |
| | Demand > supply for 1 month or more | 8 | 7 | 8 | 8 |

**Figures 5-7** through **5-10** show the potential 2060 water supply stress for each subregion under drought conditions, as shown using the notation in **Table 5-5**. The number of months exceeding the potential stress level for each subregion is listed in the yellow and red semicircles.

The Business-as-Usual scenario results for each subregion are shown in **Figure 5-7** for drought of record conditions. The low surface water flows of the drought of record combined with projected 2060 demands result in Higher Potential Stress in all subbasins except the Upper White. Supply gaps (when demand exceeds supply) range from 4 to 10 months.

The results for Strong Economy/High Water Stress, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress scenarios for each subregion are shown in **Figures 5-8** through **5-10**. All results are shown below the Business-as-Usual results for easy comparison. All scenarios show a similar level of Higher Potential Stress in nearly all subregions. As was the case under average conditions, the reduction in potential stress in the Lower Mississippi-St. Francis subregion for the Strong Economy/High Water Stress scenario compared to the other scenarios is because of the assumptions made for the source of water (i.e., more groundwater use and less surface water use).

Collectively, the results of the four planning scenarios suggest the following about the susceptibility of surface water resources:

- Projected 2060 surface water demands are expected to exceed available supply at the subregional level for at least one-third of the year in all but one subregion (the Upper White, which coincides with the South Central crop reporting district) during the drought of record, as modified by future climate conditions for certain scenarios.
- The highest potential for stress (and highest susceptibility for surface water resources) occurs in the Missouri-Nishnabotna, Chariton-Grand, Lower Missouri, and Neosho-Verdigris subregions, which generally coincide with the Northwest, North Central, West Central, and Southwest crop reporting districts.
- Southeastern Missouri, which includes the South Central, Southeast, and East Central crop reporting districts, exhibits the lowest potential for stress relative to the other regions.

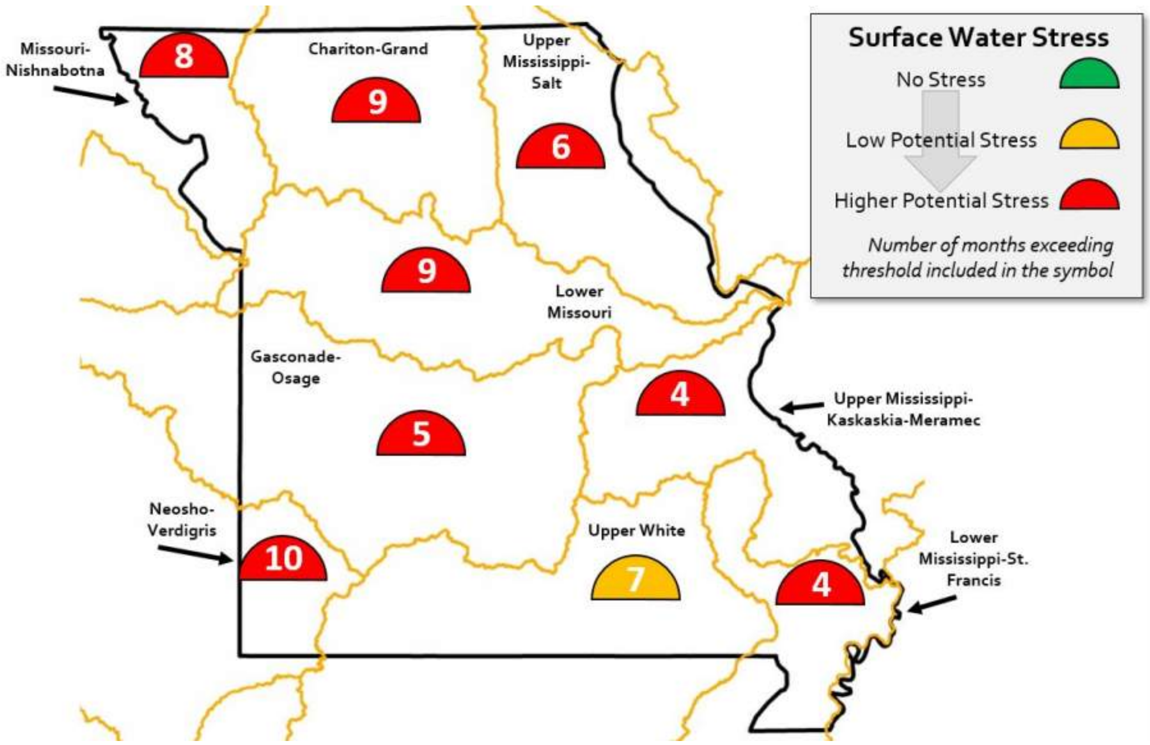



Figure 5-7. Scenario 1 Business-as-Usual Results for Drought of Record Conditions (Surface Water) (MoDNR 2020)

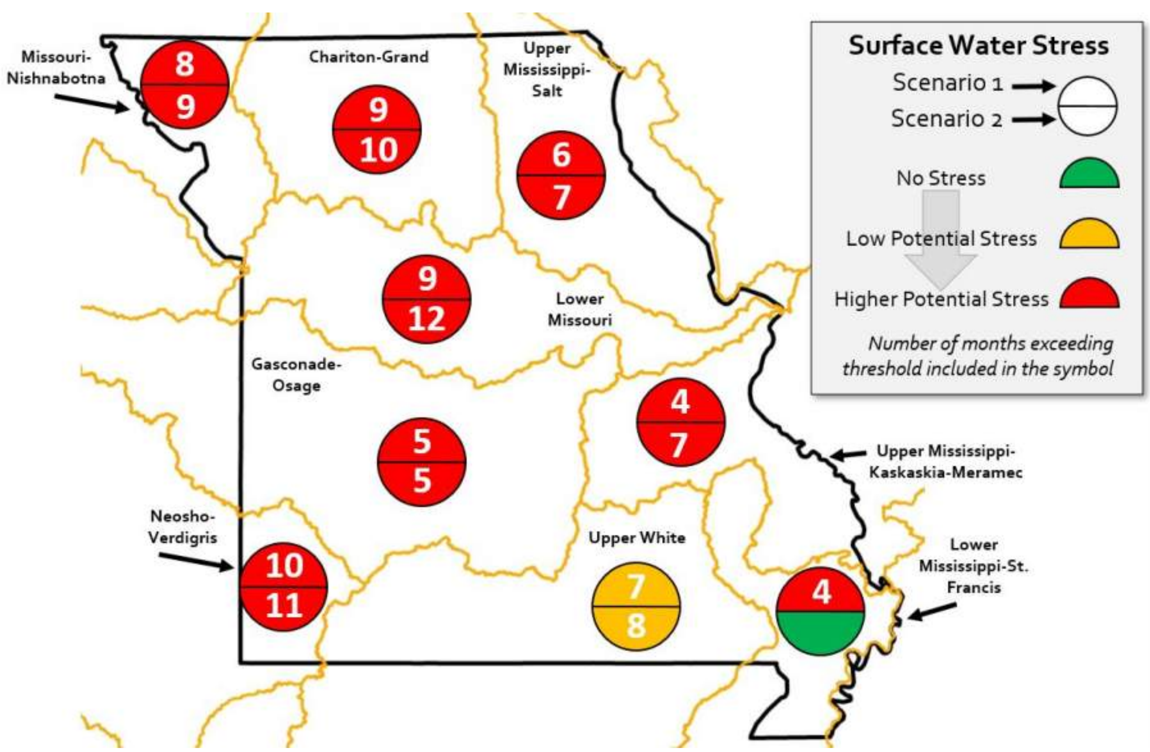



Figure 5-8. Scenario 2 Strong Economy/High Water Stress Subregion Results for Drought of Record Conditions (Surface Water) (MoDNR 2020)

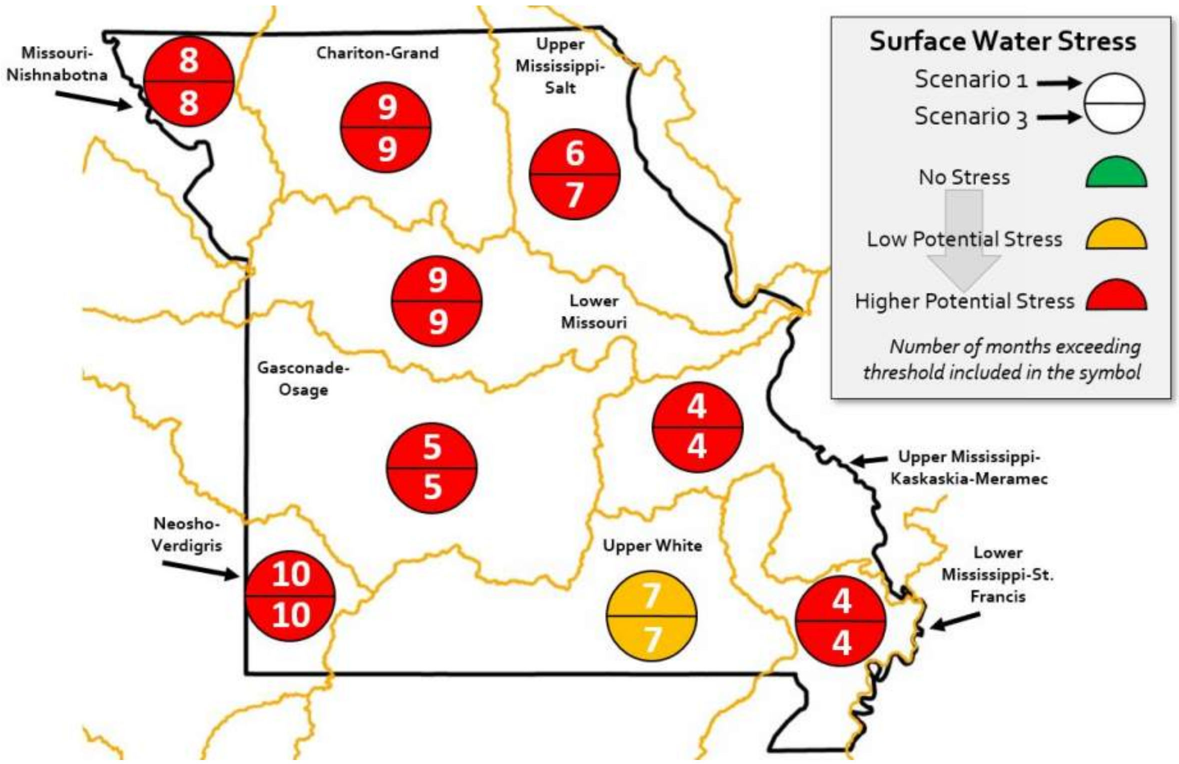



Figure 5-9. Scenario 3 Substantial Agricultural Expansion Results for Drought of Record Conditions (Surface Water) (MoDNR 2020)

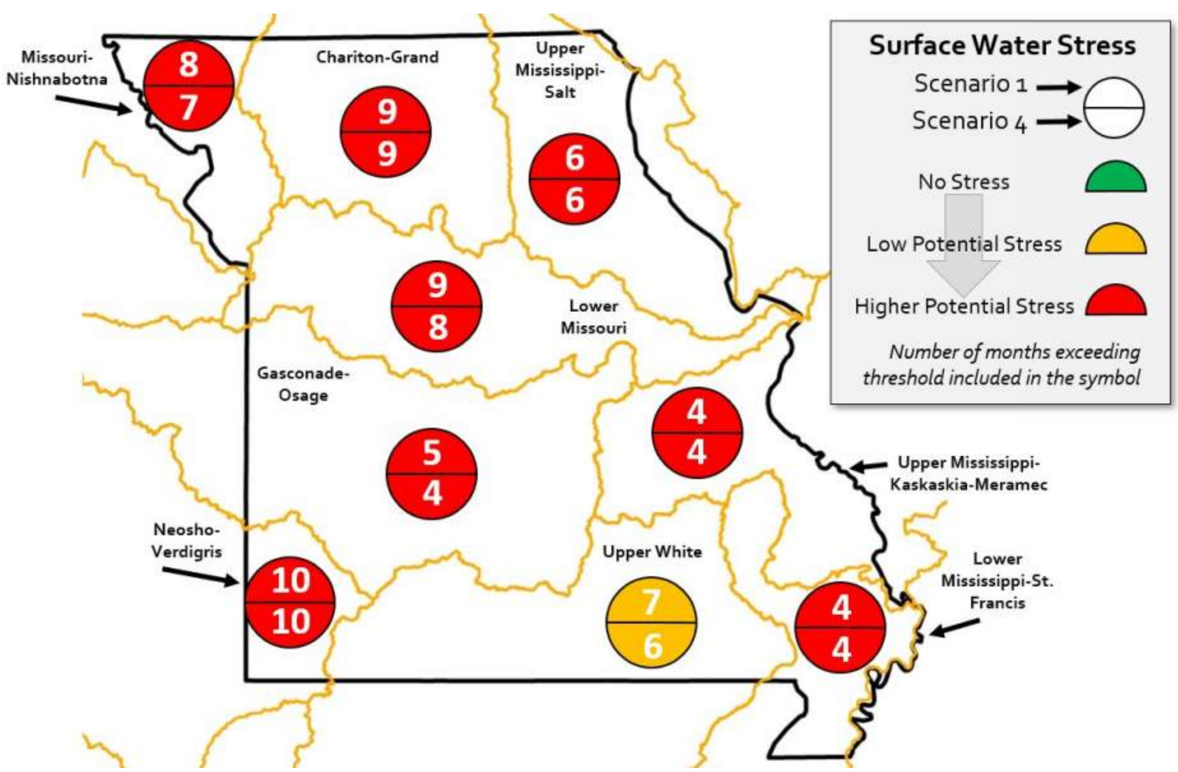



Figure 5-10. Scenario 4 Weak Economy/Low Water Stress for Drought of Record Conditions (Surface Water) (MoDNR 2020)

### 5.3.3.2 Groundwater Resources

The method used to characterize, categorize, and graphically depict the level of potential groundwater supply stress under each scenario is shown in **Table 5-6**. The method differed from the method for evaluating potential water supply stress for surface water since groundwater availability is not as easily quantified. The method considers two factors: (1) whether there is already evidence of groundwater declines in a subregion or subbasin, and (2) whether groundwater withdrawals are expected to decrease, remain the same, increase, or substantially increase as a percentage of recharge from precipitation compared to current conditions. If no declining trend in groundwater levels exists and withdrawals as a percentage of recharge from precipitation are projected to decrease or remain relatively flat, No Stress was assigned. When no trend in groundwater levels exists and withdrawals as a percentage of recharge are expected to increase, Low Stress was assigned. Low Stress was also assigned if there have been observed groundwater declines in a subregion but projected withdrawals as a percentage of recharge are expected to remain flat or decrease. An increasing level of stress, as denoted by the yellow or red boxes, was assigned when there have been observed groundwater declines in a subregion and withdrawals as a percentage of recharge are expected to increase or substantially increase. The categorization of relative potential groundwater supply stress helps to compare impacts between different scenarios and identify options and strategies to mitigate or eliminate impacts.

**Table 5-6. Identifying Potential Water Supply Stress for Groundwater**

| Condition | Analysis | Current Groundwater Levels | Withdrawals as a Percent of Recharge from Precipitation | Potential Water Supply Stress | Key |
|---|---|---|---|---|---|
| Average | Annual | No Trend | Decrease | No Stress | |
| | | No Trend | Relatively Flat | | |
| | | No Trend | Increase | Low Stress | |
| | | Declining | Flat or Decrease | | |
| | | Declining | Increase | | |
| | | Declining | Substantial Increase | Increasing | |

Average annual hydrologic conditions were considered most when evaluating scenario impacts for groundwater. However, drought conditions were also examined in groundwater aquifers, especially the more heavily used aquifers in Missouri with significant amounts of storage. As such, short-term droughts (i.e., ones that occur over the span of a year or two) typically do not impact groundwater resources to the same extent as surface water resources. Exceptions to this might include thin, surficial aquifers with relatively little storage and/or shallow wells, which may experience reduced yield or become dry when groundwater levels drop only slightly.

Furthermore, the drought of record in the mid- to late 1950s did not impact groundwater resources to the same extent as surface water resources because of the timing of precipitation. During 1954 and 1956, much of the precipitation deficit occurred in the warmer months, when groundwater recharge is already low because of high evapotranspiration. In the cooler months, precipitation was close to average for both years. Since the majority of groundwater recharge occurs in the cooler months, recharge for both years was likely to be near average even though there was significantly less annual precipitation overall.

**Figure 5-11** shows the results of all four scenarios for groundwater. Low to increasing levels of potential stress are expected in six of the nine subregions for the Business-as-Usual scenario, labeled as Scenario 1 in the figure. Slightly higher levels of stress are expected for the Strong Economy/High Water Stress scenario (2), especially in the Lower Missouri subregion, because of substantial increases in projected withdrawals

as a percentage of recharge. No Stress is expected in all subregions for the Substantial Agricultural Expansion (3) and Weak Economy/Low Water Stress (4) scenarios. Driving this result is the expected slight to moderate increase in recharge rates across the state resulting from the warmer temperatures and greater rainfall climate conditions used for the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios.

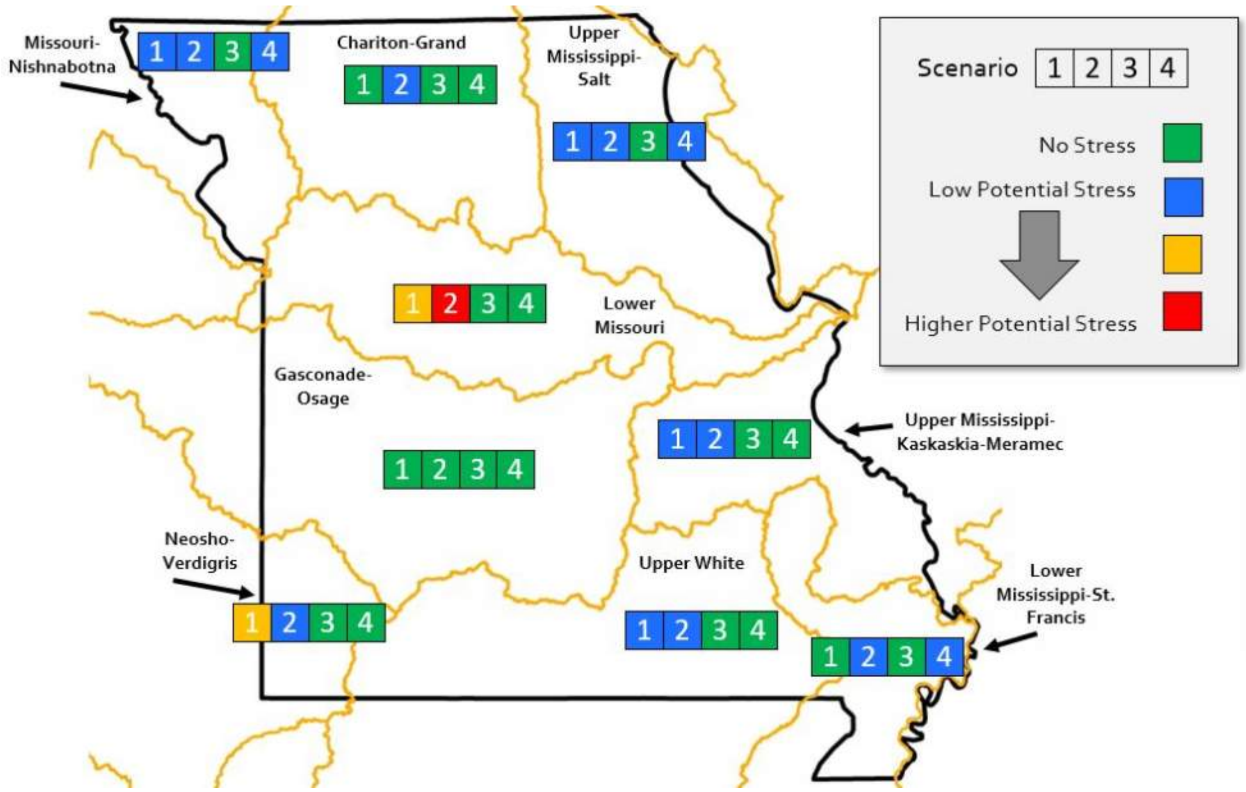



Figure 5-11. Subregion Scenario Results for Average Conditions (Groundwater) (MoDNR 2020)

The ensemble of GCMs used for the warm/wet climate condition and applied to the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios suggest that precipitation will generally increase from November through May within a range of 1 to 19 percent depending on the month and location within Missouri. In the warmer months of June through October, the opposite is expected, with precipitation declines of between 1 and 18 percent. Since most groundwater recharge occurs in the cooler months, the increase in precipitation during these months is expected to result in an overall increase in average annual recharge. This result is expected even considering the projected increase in temperatures of 3 to 4 degrees Celsius, which will increase evapotranspiration.

The hot, dry climate condition that was applied to the Strong Economy/High Water Stress scenario reflects a similar seasonal pattern. The ensemble of GCMs suggest that precipitation is expected to increase from November through May and decrease from June through September compared to current average conditions. An overall increase in annual recharge is expected in most areas.

### 5.3.4 Susceptibility of Groundwater Resources to Drought in Southern Missouri

#### 5.3.4.1 Ozark Aquifer

The Ozark Plateaus Regional Aquifer Study groundwater model developed by USGS was used to understand the impacts of extended drought on southern Missouri's groundwater resources (Clark et al. 2018). The model simulates groundwater flow from 1900 through 2015 using historical calibrated recharge

and pumping rates. Prior to 1965, the model simulates flow using two stress periods of 40 years (1900 to 1940) and 25 years (1940 to 1965). From 1965 to 1990, the model uses the average annual recharge rate for annual stress periods and the seasonal recharge rate for the 6-month stress periods between 1991 and 2015. Average annual recharge rates were calculated for 1991 to 2015 by averaging the rates for the 6-month stress periods to allow for comparison to the recharge rates reported for the 1-year stress periods.

The resulting annual recharge rate time series is shown in **Figure 5-12**. The mean average annual recharge rate for 1965 to 2015 was calculated as 3.92 inches per year (in/yr). **Table 5-7** shows the calculated percentiles for the recharge rates and **Table 5-8** shows the 5 years with the lowest recharge rates from 1965 to 2015. These are also labeled in **Figure 5-12**. The 1980 drought was chosen as the drought of interest to examine based on the low modeled recharge rate for the year (less than 10th percentile), the large extent of southern Missouri experiencing moderate to exceptional drought conditions (see **Figure 5-13**), and the availability of annual stress periods for the years surrounding 1980 in the USGS model.

**Table 5-7. Percentiles of Average Annual Recharge Rate from 1965 to 2015**

| Percentile | Annual Recharge Rate (in/yr) |
|---|---|
| 5% | 2.34 |
| 10% | 2.98 |
| 25% | 3.63 |
| Median | 3.87 |
| Mean | 3.92 |

**Table 5-8. Five Years with Lowest Recharge Rates from 1965 to 2015**

| Year | Ranking of Lowest Recharge Rate of 51 Years | Annual Recharge Rate (in/yr) | Percentile Range |
|---|---|---|---|
| 2005 | 1 | 1.73 | <5% |
| 1999 | 2 | 2.15 | <5% |
| 1980 | 3 | 2.47 | 5-10% |
| 1976 | 4 | 2.71 | 5-10% |
| 2012 | 5 | 2.82 | 5-10% |

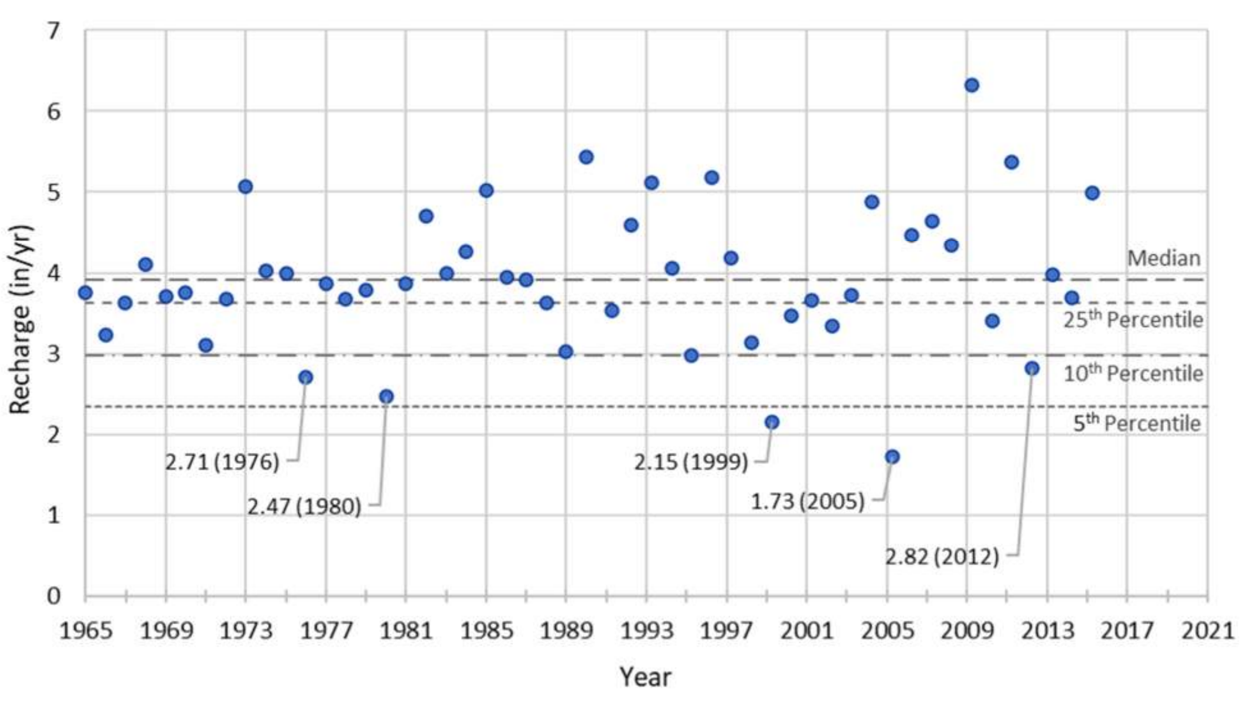



Figure 5-12. Average Annual Recharge Used in the USGS Ozark Plateaus Aquifer System Groundwater Model

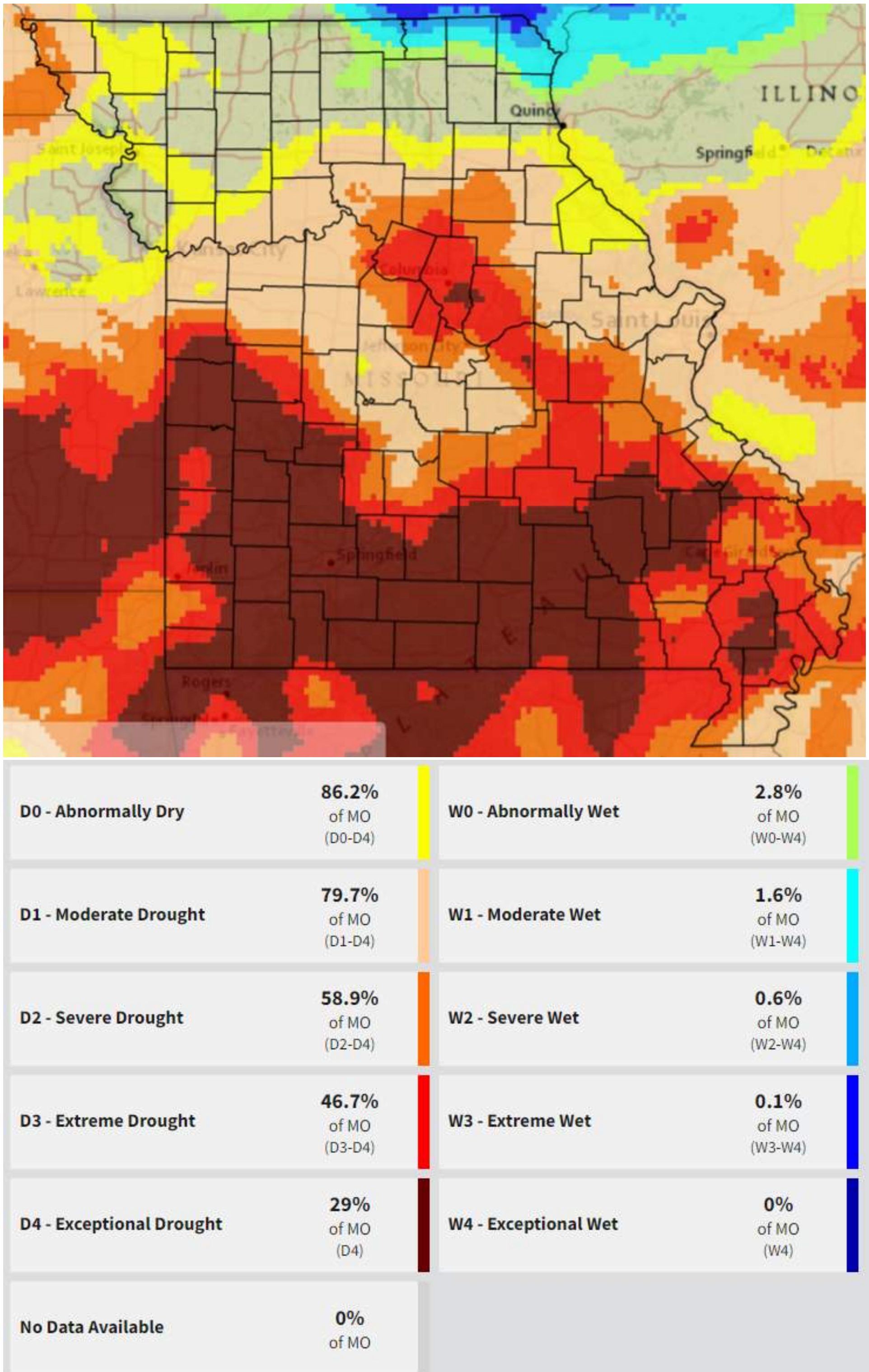



Figure 5-13. Drought Monitor Map in February 1981 (NOAA 2021)
Source: Drought.gov

To assess vulnerability to an extended drought, a model simulation was performed where the recharge rates in the model for 1980 were applied to the 1981 and 1982 simulation years. This simulation represents a *what if* scenario to assess the impacts to groundwater levels, assuming the much lower than average precipitation

and recharge of 1980 had continued for 1981 and 1982. In the actual historical simulation, recharge rates recover to average levels in 1981 and 1982, to 3.87 and 4.71 in/yr, respectively. The resulting change in groundwater levels (potentiometric surface) in the Lower Ozark Aquifer from the end of 1979 to the end of 1982 in this drought scenario is shown in **Figure 5-14**. Groundwater level declines in the western portion of the model were minimal, mainly ranging from 0 to 10 feet. In eastern Missouri, groundwater level declines ranged from 0 to 30 feet, with losses exceeding 30 feet in some areas.

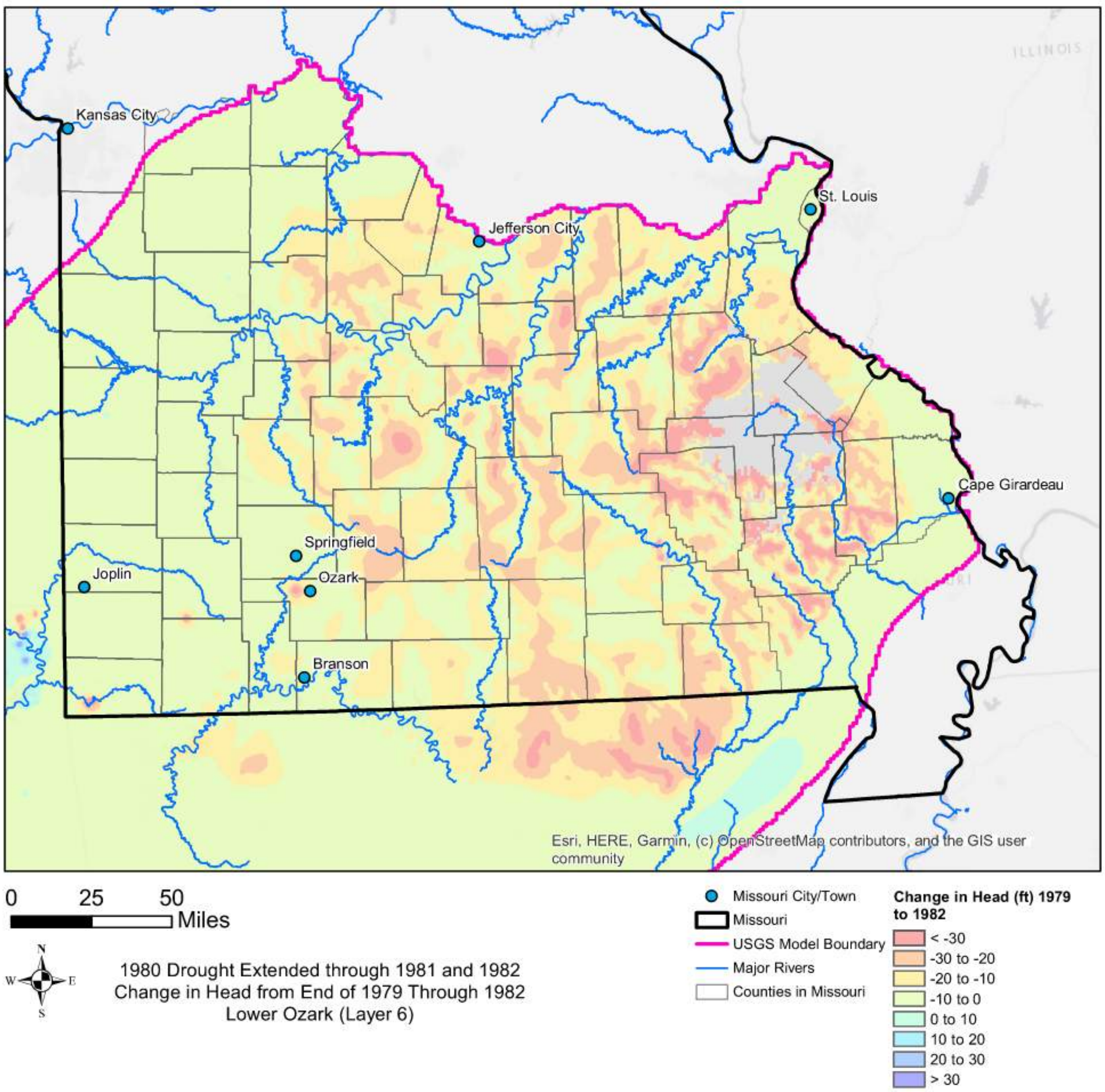



Figure 5-14. Change in Groundwater Levels (Head) from 1980 to 1982 Under Extended 1980 Drought Conditions

To understand how the magnitude of simulated groundwater level declines compared to historical fluctuations, the difference between drawdown in the drought scenario and drawdown in the historical scenario over the same 3-year period was calculated and is shown in **Figure 5-15**. In the drought scenario, an additional 10 to 40 feet of groundwater level declines are observed in the Lower Ozark Aquifer in much of eastern Missouri. Some areas exceed 50 feet of additional declines. The western side of the model shows little difference in change between the drought and historical scenarios. The difference in model-assigned recharge rates for 1980 and 1982 is shown in **Figure 5-16**.

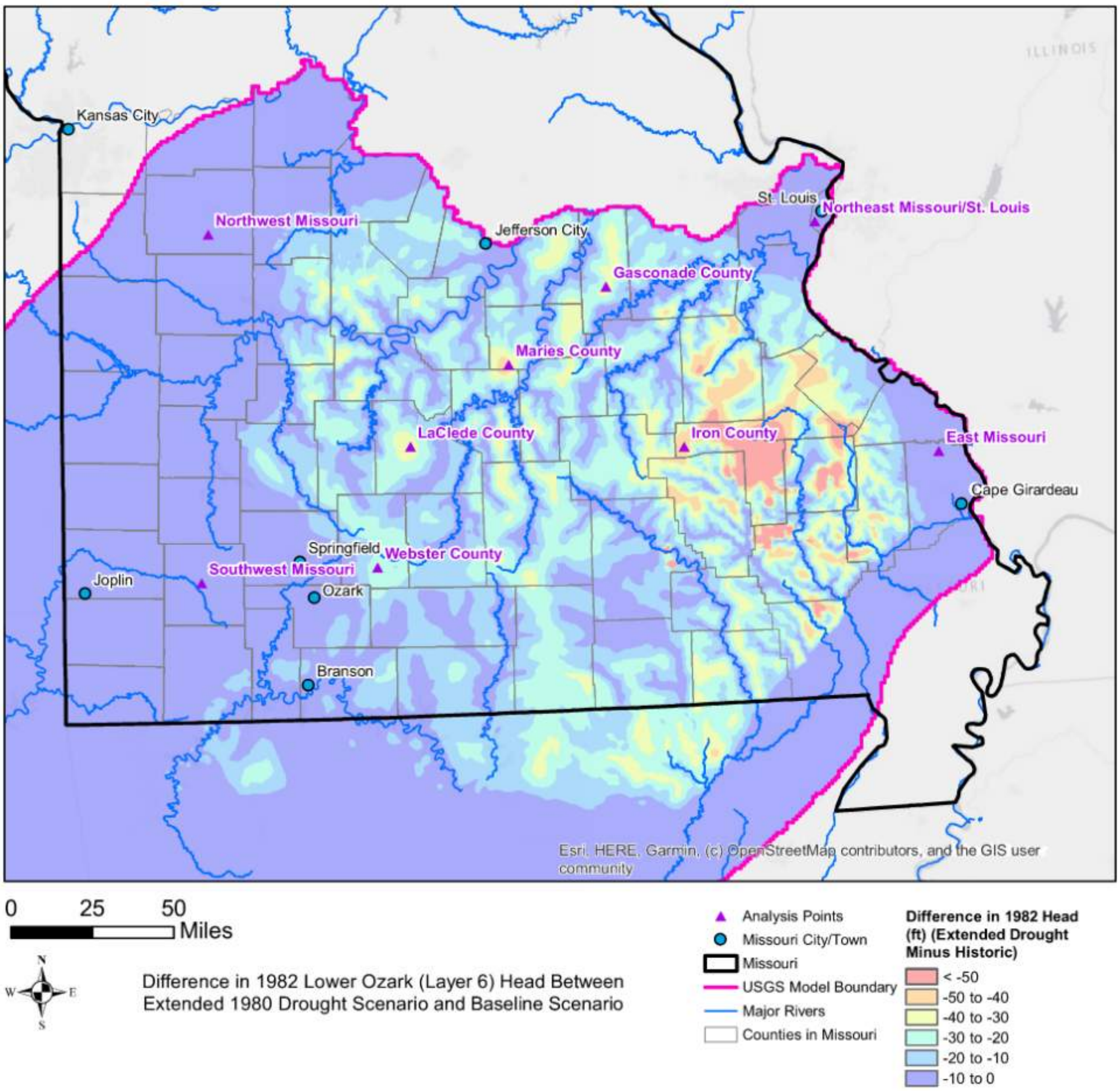



Figure 5-15. Difference in Change in Head Between Extended 1980 Drought Scenario and Historical Scenario from 1980 to 1982

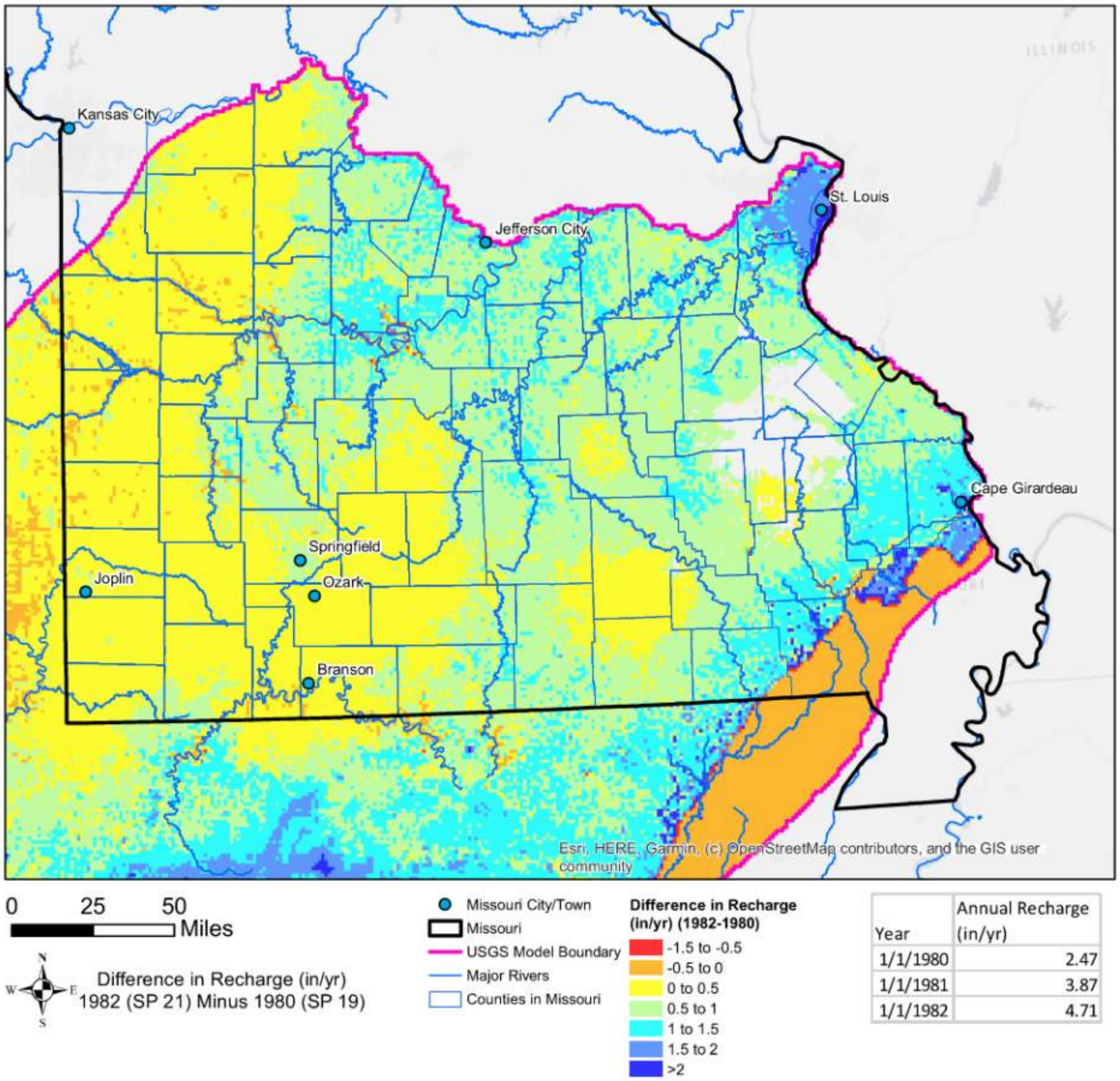



Figure 5-16. Difference in Recharge Rates Between 1982 and 1980 (positive numbers represent areas of higher recharge rates in 1982 compared to 1980; negative numbers represent areas of lower recharge rates in 1982 compared to 1980)

To understand the potential implications of drought-related groundwater level declines on water supplies, simulated heads were compared to representative well depths in portions of the state where the largest simulated declines in groundwater levels were observed. For this analysis, the 1980 drought was extended for 10 years to 1990 to represent an extreme drought scenario. While this scenario may be deemed unrealistic based on historical data, the purpose was to understand where more severe groundwater declines may occur during drought conditions, indicating a higher level of susceptibility to drought. Simulated Lower Ozark Aquifer groundwater levels at nine points of interest throughout the state, as shown in purple in **Figure 5-15**, were identified from the model and plotted over the 10-year simulation, as shown in **Figure 5-17**. Wells withdrawing from the Lower Ozark Aquifer in the central and eastern parts of the model area are more susceptible to impacts to drought than in the western portion. The Ozark Aquifer becomes thicker, providing much more groundwater storage moving radially away from the St. Francois Mountains area in St. Francois, Iron, Madison, and Washington counties. In **Figure 5-17**, the representative

wells in areas where the Ozark Aquifer is approximately 1,000 feet or more thick generally show less than 15-foot declines over 10 years compared to the 30- to almost 60-foot declines in representative wells where the Ozark Aquifer is less than 1,000 feet thick.

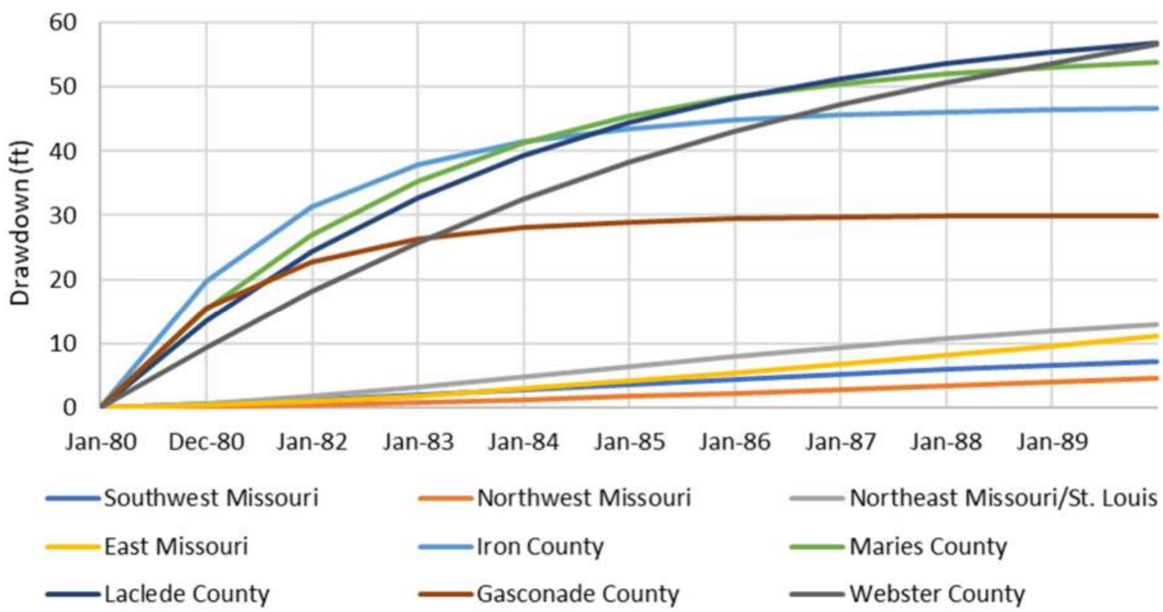



Figure 5-17. Simulated Groundwater Declines in Select Locations (locations are shown in Figure 5-15) throughout the Ozark Aquifer Model, 1980 Drought Extended 10 Years

However, a comparison of groundwater declines in areas with the most extreme declines to representative public supply wells indicates that even in an extreme 10-year drought, groundwater supplies may not be at significant risk and are not susceptible to impacts from an extended drought. As shown in **Figure 5-18**, groundwater declines of nearly 60 feet in Laclede and Webster counties and 30 feet in Gasconade County result in water levels that are still above the open interval of representative wells in these counties. In this case, depending on the elevation at which well pumps are set, pumps may need to be lowered to maintain a groundwater level at least 10 to 20 feet above the pump.

The subregional groundwater budgets detailed in the 2020 Missouri Water Resources Plan also demonstrate there is a significant amount of groundwater stored in the Ozark Aquifer, especially compared to recharge from precipitation and current and projected groundwater withdrawals. **Figure 5-19** shows the groundwater budget for the Gasconade-Osage subregion using a generalized representation of the major aquifers present. Over 129,000 billion gallons of potable groundwater is estimated to be stored in the Ozark Aquifer of this subregion. Recharge from precipitation (under average annual conditions) is estimated to be 1.9 billion gallons per day while projected withdrawals in 2060 for all uses were estimated to be less than 0.1 billion gallons per day (or just under 100 MGD).


Figure 5-18. Simulated Groundwater Level Declines and Representative Well Depths in Laclede, Webster, and Gasconade Counties, 1980 Drought Extended 10 Years

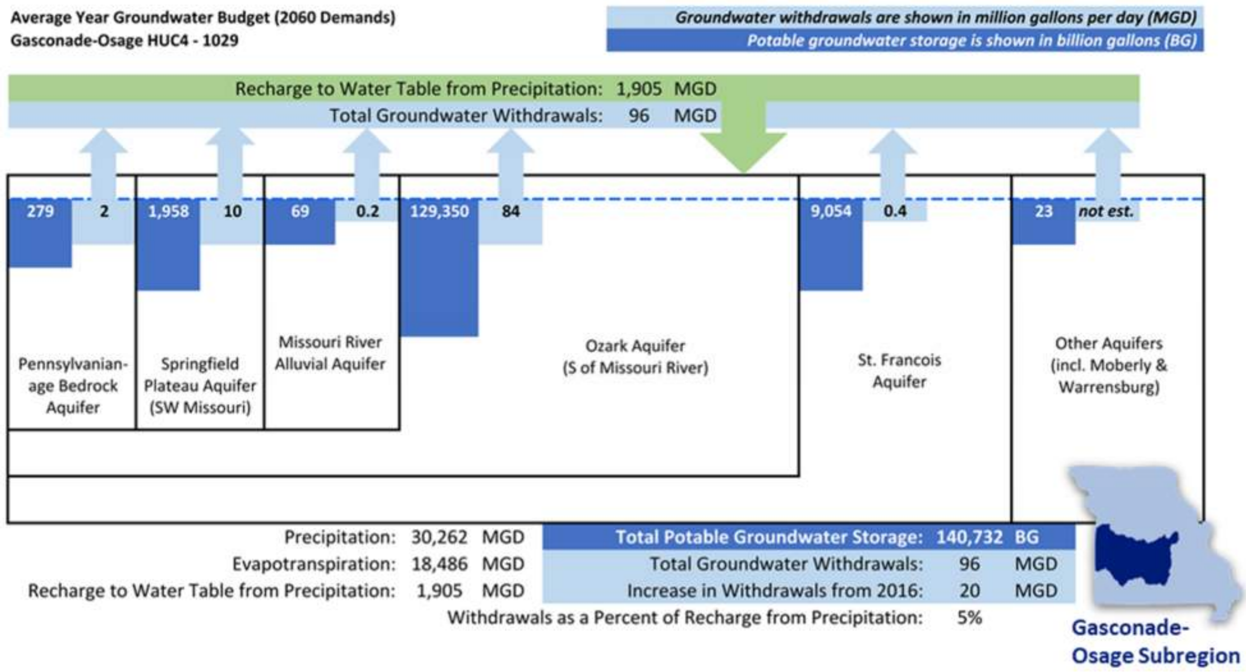



Figure 5-19. Groundwater Budget Gasconade-Osage Subregion (MoDNR 2020)

#### 5.3.4.2 Bootheel Region

The Bootheel region of Missouri was not modeled as part of the Ozark Plateau model and therefore impacts of drought in this region could not be analyzed using the model. Historical groundwater levels monitored by USGS were reviewed to assess if any notable declines have occurred that could be related to decreased recharge and potential increased pumping associated with periods of drought. Most wells in this region withdraw from the Southeast Lowlands Alluvial Aquifer; however, some wells withdraw from the deeper Wilcox or McNairy aquifers. In the Bootheel region, representative wells have not exhibited notable sustained groundwater declines since monitoring began in 1956, as shown in **Figure 5-20**. Comparatively, some wells in neighboring Arkansas have exhibited a trend of declining water levels owing to sustained, large withdrawals over the past decade.

To assess the impact of drought years in this area, USGS-monitored water levels from two representative wells were plotted in **Figure 5-21** along with recharge assigned to the Ozark Plateaus aquifer model. While estimated recharge to the alluvial aquifer of the Bootheel region is likely to differ from that of the Ozark Aquifer, the Ozark Aquifer model recharge rate was used as a surrogate since it was readily available and could be generally used to identify the likely dry years when recharge to the alluvial aquifer was also expected to be below average.

The drought years 1971, 1976, and 1980 had the eighth, fourth, and third lowest recharge rates, respectively, of the 51 years of data simulated in the Ozark Plateaus aquifer model. On average, groundwater levels illustrate seasonal patterns of drawdown in the growing season from April to September and recovery in the wetter, non-growing season from October to March. Water levels in the drought years specified did not recover as much in the wetter, winter portion of the year but did rebound within a year or two under average recharge conditions.

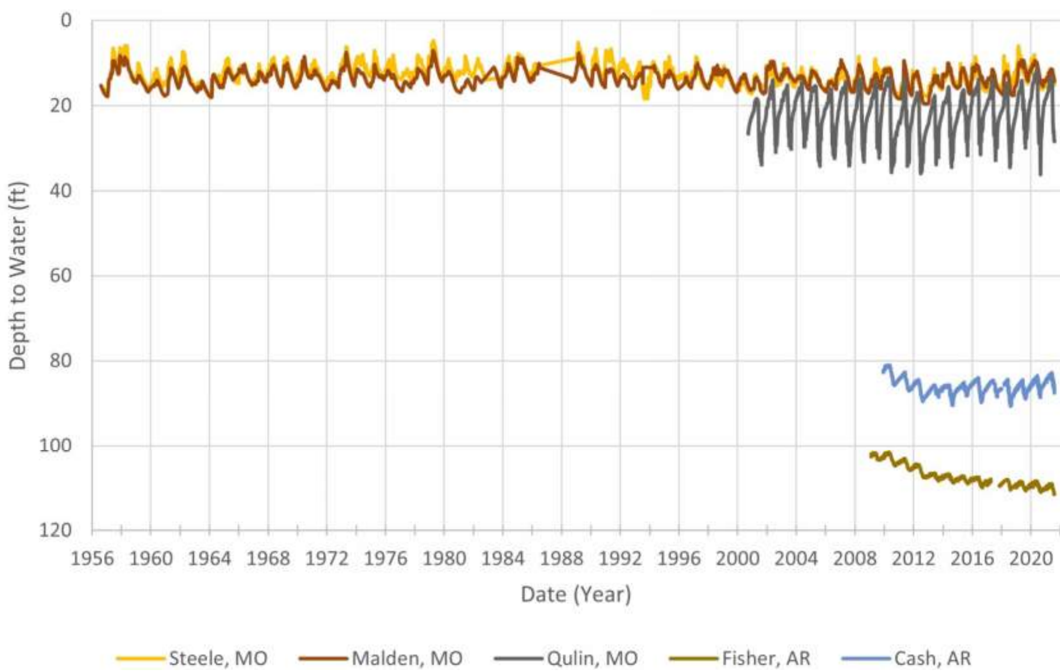
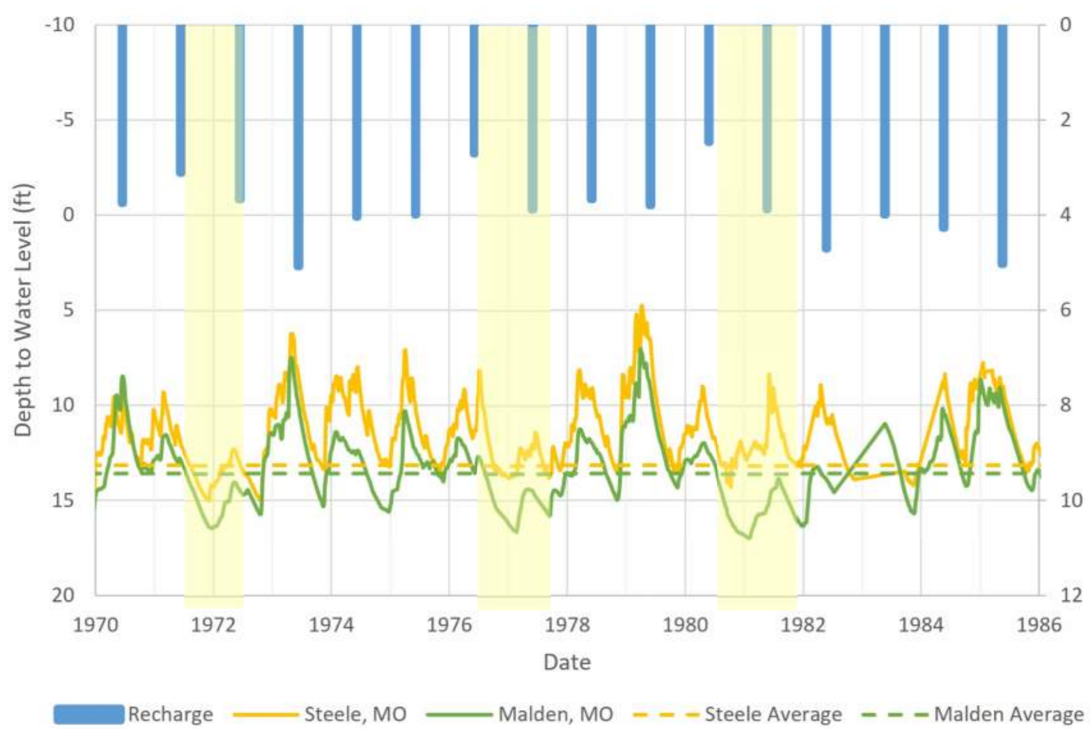



Figure 5-20. Groundwater Levels in Wells Screened in the Southeast Lowlands Alluvial Aquifer in Missouri and Arkansas (USGS 2021)




*Recharge assigned to the Ozark Plateaus aquifer model was used to identify expected periods of lower recharge to the Alluvial aquifer of the Bootheel region

Figure 5-21. Water Levels and Recharge in Two Bootheel Region Alluvial Wells (yellow-shaded regions highlight seasonal declines and decreased recovery in winter periods during drought years)

### 5.3.5 Susceptibility Summary

Based on the original assessment of susceptibility from the 2002 Missouri Drought Plan (MoDNR 2022), the water budgets and scenario planning developed as part of the 2020 Missouri Water Resources Plan, and the additional modeling and analysis described in Sections 5.3.3 and 5.3.4, relative rankings of susceptibility were established for each crop reporting district. The relative rankings are shown in **Table 5-9**.

**Table 5-9. Drought Susceptibility Ranking by Crop Reporting District**

| Crop Reporting District | Susceptibility Ranking |
|---|---|
| Central | 4 |
| East Central | 3 |
| North Central | 9 |
| Northeast | 7 |
| Northwest | 8 |
| South Central | 2 |
| Southeast | 1 |
| Southwest | 5 |
| West Central | 6 |

Note: A ranking of 1 equals the lowest relative drought susceptibility and a ranking of 9 equals the highest.

## 5.4 Regional Vulnerability

For the purposes of this plan, drought vulnerability is defined as the combination of four elements of drought: likelihood, susceptibility, impact, and resilience. A region that has high likelihood (probability) of experiencing drought conditions has higher vulnerability than an area with a low likelihood of drought conditions. Susceptibility depends on the sources and amount of water available for use and the demands on those sources. An area with multiple sources of water and large amounts of storage is less susceptible to drought than an area with a single source of water and limited storage of water that can be used in the event of a drought. The total impact of drought depends on the potential for environmental, economic, and social impacts. A heavily agricultural region or a region with a high population will have more significant impacts than a forested area with limited agriculture and low population. Resilience to drought is based on the ability to adjust in times of drought. Elements such as water system interconnections, conjunctive use capabilities, and the Social Vulnerability Index provide insight into which areas are best able to respond during drought to minimize potential impacts. The combination of these four parameters allows for relative vulnerability to be determined by region.

Vulnerability to drought also varies by water source; groundwater and surface water sources are impacted and respond to drought differently. Groundwater sources are generally not impacted directly by drought unless it is a severe, prolonged drought that forces farmers and water utilities to rely on groundwater in increasing quantities to meet irrigation and water supply needs for an extended period.

Conversely, surface water sources may be impacted after a short period of drought. However, the degree of impact depends on the type of surface water source; small ponds, reservoirs, and streams are likely to have noticeable impacts more rapidly than large lakes, reservoirs, and rivers. A significant, prolonged drought event has the potential to severely diminish surface water sources if no effective mitigation measures are available and implemented. Surface water sources are also used for other purposes besides potable and irrigation water supply (e.g., shipping/inland navigation, thermoelectric cooling water, hydroelectric power generation) and water withdrawals can be limited by ecological concerns as well. Once a drought is over

and precipitation returns to near-normal amounts, surface water sources typically start to recover quickly, although it may take considerable time to return to pre-drought conditions.

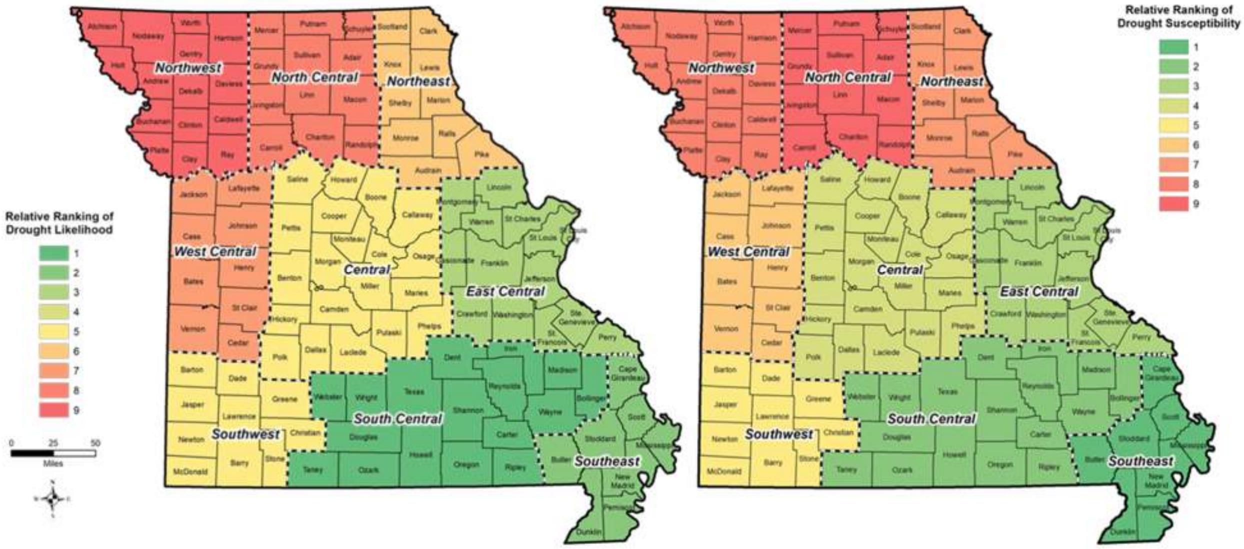
The relative rankings of likelihood, susceptibility, impact, and resilience by crop reporting district are shown in **Table 5-10**. The relative rankings for each element were added together and the crop reporting districts were re-ranked to develop the overall vulnerability rankings, which are also shown in **Table 5-10**. The overall vulnerability rankings generally increase from the Southeast crop reporting district, where overall vulnerability is the lowest, to the North Central, Northeast, and Northwest districts, where overall vulnerability is the highest.

Likelihood and susceptibility rankings are shown in **Figure 5-22.** Impact and resilience rankings are shown in **Figure 5-23**. Overall relative vulnerability rankings are shown in **Figure 5-24**. By identifying and understanding regional differences in each of these elements and in the overall relative vulnerability of each region, mitigation and response strategies can be appropriately considered and selected to address the elements that most contribute to drought vulnerability in each region. The strategies to prepare for and respond to drought are further developed in Section 6, Drought Mitigation and Response.

**Table 5-10. Relative Ranking of Likelihood, Susceptibility, Impact, Resilience, and Overall Vulnerability by Crop Reporting District**

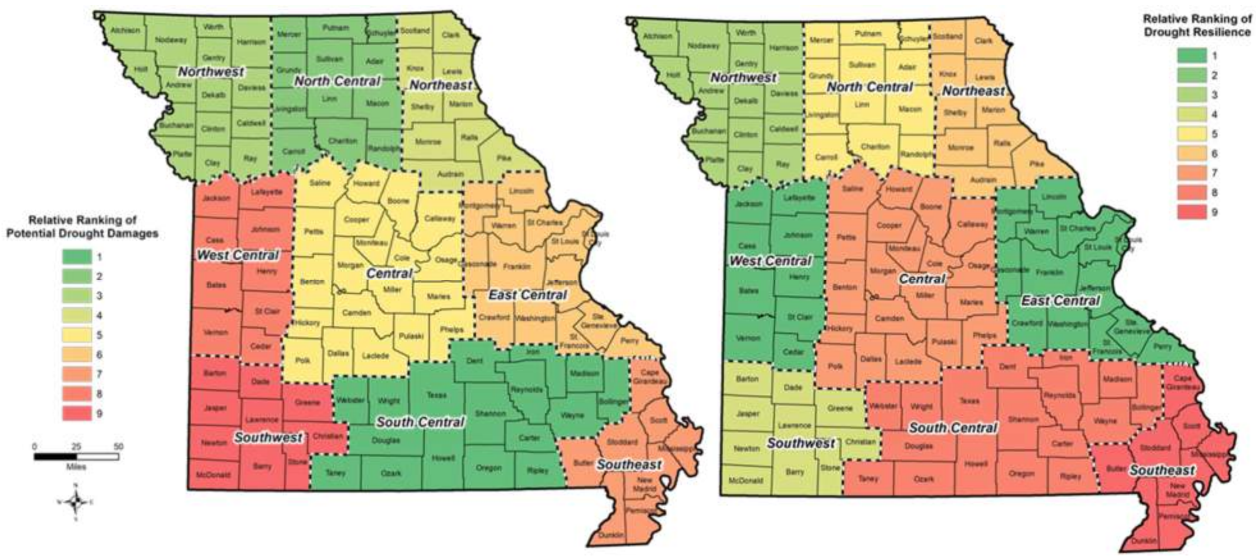
| Crop Reporting District | Likelihood Ranking | Susceptibility Ranking | Impact Ranking | Resilience Ranking | Overall Vulnerability Ranking |
|---|---|---|---|---|---|
| Central | 4 | 4 | 5 | 6 | **3** |
| East Central | 3 | 3 | 6 | 1 | **2** |
| North Central | 8 | 9 | 2 | 5 | **9** |
| Northeast | 6 | 7 | 4 | 6 | **7** |
| Northwest | 9 | 8 | 3 | 3 | **7** |
| South Central | 1 | 2 | 1 | 8 | **1** |
| Southeast | 2 | 1 | 7 | 9 | **3** |
| Southwest | 4 | 5 | 9 | 4 | **5** |
| West Central | 7 | 6 | 8 | 1 | **5** |

Note: A ranking of 1 equals the lowest relative drought likelihood, susceptibility, impact, or overall vulnerability and a ranking of 9 equals the highest. A ranking of 1 equals the highest relative resiliency and a ranking of 9 equals the lowest. When there was a tie in the rankings, the same ranking was assigned to each district.



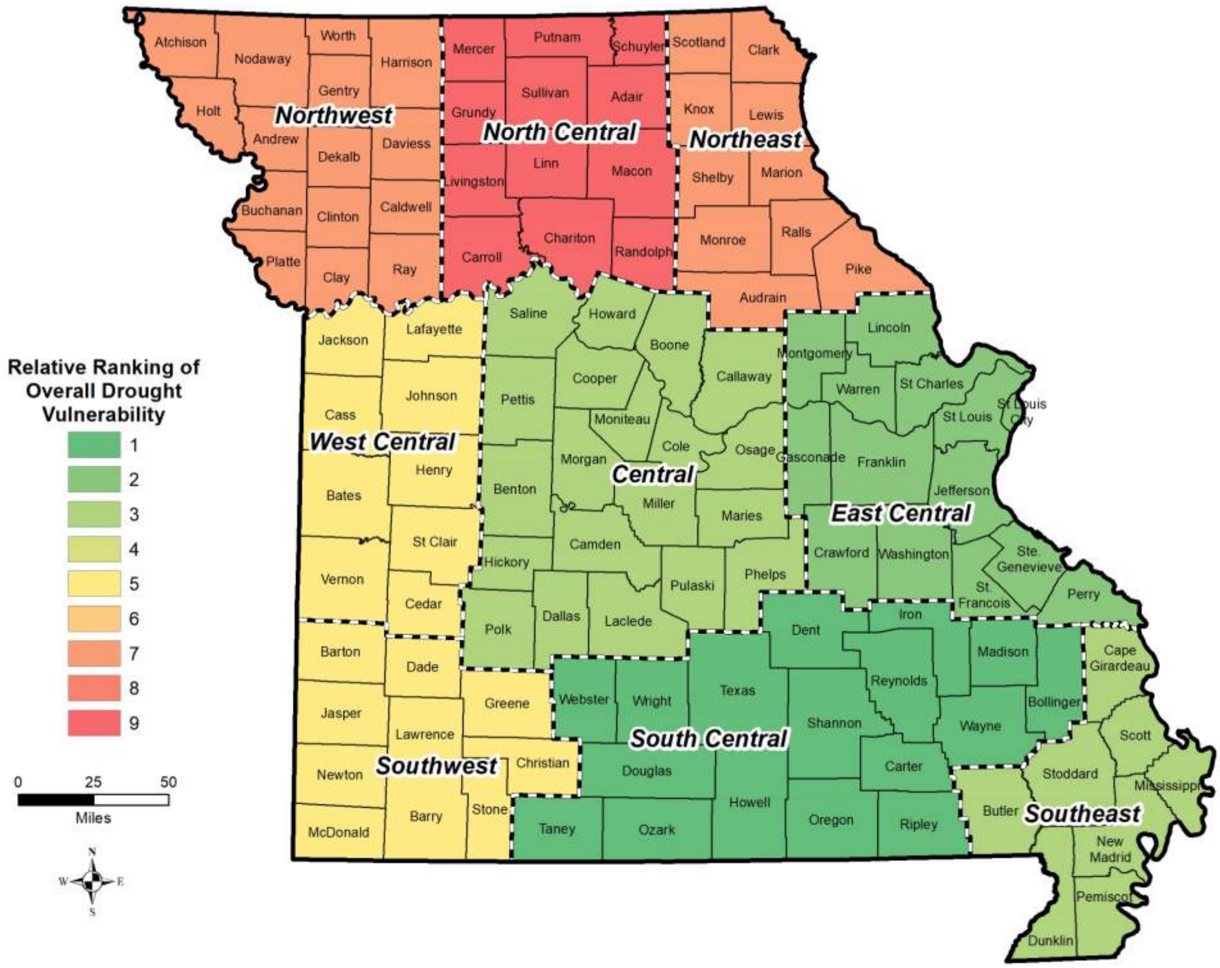

Note: A ranking of 1 equals the lowest relative drought likelihood or susceptibility and a ranking of 9 equals the highest.

Figure 5-22. Relative Ranking of Drought Likelihood and Susceptibility by Crop Reporting District.




Note: A ranking of 1 equals the lowest relative drought impact (potential damages) and a ranking of 9 equals the highest, while a ranking of 1 equals the highest relative resiliency and a ranking of 9 equals the lowest. Districts with the same color were tied in the rankings.

Figure 5-23. Relative Ranking of Drought Potential Drought Damages (Impact) and Resilience by Crop Reporting District




Note: A ranking of 1 equals the lowest relative drought likelihood, susceptibility, impact (potential damages), resilience, or overall vulnerability and a ranking of 9 equals the highest. Districts with the same color were tied in the rankings.

Figure 5-24. Relative Ranking of Overall Drought Vulnerability by Crop Reporting District

## 5.5 References Cited

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Fisher, AK: https://waterdata.usgs.gov/nwis/inventory/?site_no=352726090523101&agency_cd=USGS.

Steele, MO: https://waterdata.usgs.gov/mo/nwis/inventory/?site_no=360425089485001&agency_cd=USGS.

Malden, MO: https://waterdata.usgs.gov/mo/nwis/inventory/?site_no=362955089581801&agency_cd=USGS.

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# Section 6 Drought Mitigation Capabilities

## 6.1 Introduction

Local, state, and federal organizations all play an important role in preparing for and responding to drought. Federal agencies provide technical resources and are sources of funding. State agencies monitor for drought conditions, provide technical and financial resources, and help coordinate the response. Local agencies are responsible for implementing measures to mitigate the effects of drought.

This section discusses the capabilities of federal and state agencies involved in drought response and summarizes their roles and responsibilities prior to, during, and following a drought. The composition and roles of state drought response committees and teams are also outlined. Local drought mitigation capabilities are summarized based on an assessment of several small, medium, and large water utilities. Funding opportunities for risk reduction, building resiliency, and mitigating impacts from drought are identified.

### Overview of Section 6 Drought Mitigation Capabilities

This section introduces Missouri's drought mitigation goals and summarizes state, federal, and local capabilities, roles, and responsibilities. Subsections are organized as follows:

- Section 6.2 Mitigation Goals – identifies goals to prepare for drought (proactive measures) and respond to drought (mitigation measures).
- Section 6.3 Federal and State Drought Mitigation Capabilities – identifies federal and state agencies with capabilities for drought planning and response. Discusses roles and responsibilities. Identifies state funding that can be used for drought mitigation and response.
- Section 6.4 Local Drought Mitigation Capabilities – identifies the spectrum of local capabilities for drought preparation and response. Identifies common gaps in local drought planning and response capabilities, based on previous droughts.
- Section 6.5 Drought Mitigation Funding – identifies and summarizes funding opportunities for drought mitigation and response.

## 6.2 Mitigation Goals

Missouri's drought mitigation and response goals are broad-based and describe the overall direction that the state will take to reduce impacts from drought. Each goal is supported by specific recommendations and mitigation actions described in Sections 7 and 8. These goals also align with and support the state's hazard mitigation goals and objectives, as identified in the State Hazard Mitigation Plan (Missouri Department of Public Safety Emergency Management 2018). Drought mitigation and response goals for Missouri are listed in **Table 6-1**.

**Table 6-1. Missouri Drought Mitigation and Response Goals**

| Category | Goal |
|---|---|
| Reduce Impacts | 1. Reduce the impacts from drought to Missouri's economy, people, state and local assets, and environment. |
| Increase Public Awareness | 2. Increase public awareness and provide education about drought planning, mitigation, and response. |
| Enhance Resiliency | 3. Promote and help develop opportunities to enhance resiliency to drought through interconnections; identify backup supplies, water reuse, and other means that increase sources of supply. |
| Promote Water Conservation | 4. Encourage water conservation and promote efficient water use. |
| Adapt to Changing Climate | 5. Evaluate and prepare for impacts from changing climate conditions, including the potential for increased frequency, duration, and severity of drought events. |
| Improve Monitoring | 6. Improve water availability monitoring, stay informed of evolving drought monitoring programs, and continue to refine triggers for initiating and terminating drought mitigation and response programs. |
| Plan for Responses | 7. Develop, review, and update drought response plans and procedures. |
| Clarify Roles and Responsibilities | 8. Clarify the roles, responsibilities, and capabilities of state and other agencies in preparing for and responding to drought conditions. |

## 6.3 Federal and State Drought Mitigation Capabilities

### 6.3.1 Federal Drought Mitigation Capabilities

During drought emergencies, Missouri may request assistance (material and personnel support) in obtaining data, information, loans, and/or grants from the following federal government organizations:

- Federal Emergency Management Agency (FEMA)
- General Services Administration
- National Oceanic and Atmospheric Association
- Small Business Administration
- U.S. Army Corps of Engineers
- U.S. Department of Agriculture (USDA)
- U.S. Department of Commerce
- U.S. Department of Labor
- U.S. Department of the Interior
- U.S. Environmental Protection Agency

While each of these federal organizations may be called upon to provide resources, organizations with extensive or recently updated programs are highlighted below.

#### *U.S. Department of Agriculture*

USDA offers programs to assist with drought recovery as well as risk reduction and resiliency related to drought. Disaster assistance programs are available in counties with disaster designations. The Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency loans and disaster

assistance programs available to crop and livestock producers in designated counties and their contiguous, neighboring counties. These designations may include a USDA secretarial disaster designation, a presidential major disaster or presidential emergency declaration, or a Farm Service Agency (FSA) Administrator's Physical Loss Notification and Quarantine designation. Disaster designations must be requested by a governor or the governor's authorized representative or by an FSA state executive director. **Table 6-2** summarizes the drought assistance provided by various USDA agencies.

**Table 6-2. USDA Disaster Assistance Programs**

| Disaster Program | Agency[1] | Description |
|---|---|---|
| Crop Insurance | RMA | Provides indemnity payments to growers who purchased crop insurance for production and quality losses related to drought, including losses from an inability to plant caused by an insured cause of loss. |
| Conservation Reserve Program (CRP) Haying and Grazing | FSA | Provides for emergency haying and grazing on certain CRP practices in a county designated as D2 or higher on the U.S. Drought Monitor, or in a county where there is at least a 40 percent loss in forage production. |
| Emergency Assistance for Livestock, Honeybees and Farm-Raised Fish Program (ELAP) | FSA | Provides assistance to eligible owners of livestock and producers of honeybees and farm-raised fish for losses. |
| Emergency Conservation Program (ECP) | FSA | Provides funding and technical assistance for farmers and ranchers to restore farmland damaged by natural disasters and for emergency water conservation measures in severe droughts. |
| Emergency Forest Restoration Program (EFRP) | FSA | Provides funding to restore privately owned forests damaged by natural disasters. Assistance helps landowners carry out emergency measures to restore forest health on land damaged by drought disasters. |
| Farm Loans | FSA | Provides emergency and operating loans to help producers recover from production and physical losses due to natural disasters and can pay for farm operating and family living expenses. |
| Environmental Quality Incentives Program (EQIP) | FSA | Provides agricultural producers with financial resources and assistance to plan and implement improvements on the land in support of disaster recovery and repair and can help mitigate loss from future natural disasters. Assistance may also be available for emergency animal mortality disposal from natural disasters. |
| Emergency Watershed Program (EWP-Recovery) | NRCS | Offers vital recovery options for local communities to help people reduce hazards to life and property caused by droughts. |
| Emergency Community Water Assistance Grants | RD | Offers grants to rural areas and towns with populations of 10,000 or less to construct waterline extensions, repair breaks or leaks, address maintenance necessary to replenish the water supply, or construct a water source, intake or treatment facility. |

[1]Agency definitions: RMA – Risk Management Agency; FSA – Farm Service Agency; NRCS – Natural Resources Conservation Service; RD – Rural Development

Emergency farm loans and disaster debt set-asides are provided to help producers with recovery from production and physical losses in agricultural disaster areas. Secretarial agricultural disaster designations immediately trigger the availability of low-interest FSA emergency loans to eligible producers in all primary and contiguous counties. FSA borrowers that are unable to make scheduled payments on debts may be authorized to have certain set-asides in primary or contiguous counties. Farmers in eligible counties have 8 months from the date of the declaration to apply for loans to help cover part of their actual losses. FSA will consider each loan application on its own merits, considering the extent of losses, security available, and repayment ability.

### *Federal Emergency Management Agency*

During a presidentially declared drought emergency, FEMA may provide emergency response teams in the state to assist in coordinating federal assistance. Additionally, FEMA administers the Hazard Mitigation Assistance (HMA) program, a nationally competitive grant program, which may provide 75 percent of total project costs for projects that reduce or mitigate disaster risks and/or losses in areas with a presidentially declared major disaster. Under HMA, drought assistance may be provided through the Hazard Mitigation Grant Program (HMGP) and Building Resilient Infrastructure and Communities (BRIC) program. HMGP provides funding to state, local, tribal, and territorial governments so they can rebuild in a way that reduces or mitigates future disaster losses in their communities. The BRIC program supports hazard mitigation projects by reducing the risks of disasters and natural hazards.

In August 2021, as part of pandemic response disaster declarations, HMGP made available $25.1 million in funding for Missouri to increase resilience to climate change impacts. Eligible mitigation projects for this funding may include projects aimed at reducing risks associated with drought (U.S. Department of Homeland Security 2021).

## 6.3.2 State Drought Mitigation Capabilities

During drought emergencies, Missouri may call upon the following state organizations to support local governments:

- Missouri Department of Agriculture (MDA)
- Missouri Department of Conservation
- Missouri Department of Economic Development
- Missouri Department of Public Health and Senior Services
- Missouri Department of Natural Resources
- Missouri Department of Public Safety
- Missouri Department of Social Services
- University of Missouri State Climatologist
- University of Missouri Extension

Most state assistance is available only after a state or regional declaration of a drought emergency by the governor or local authorities, although some state assistance may be released for local use prior to issuance of a formal drought declaration. Each of these state organizations provide a number of resources, including assessments of drought damage and delegation of staff for drought committees. Organizations with extensive or recently updated programs are highlighted below.

### *Missouri Department of Natural Resources*

To meet Missouri's comprehensive water needs and monitor potential future and current drought conditions, the Missouri Department of Natural Resources (MoDNR) Water Resources Center's staff of hydrologists, geologists, and engineers monitors climate, weather, and streamflow conditions.

The director of the Water Resources Center serves as the chair of the state Climate and Weather Committee (CWC), which may be called to convene to monitor climatic conditions in emerging droughts. The director of MoDNR or their designee serves as the chair of the Drought Assessment Committee (DAC). In drought emergencies, the director of MoDNR serves as the chair of the Drought Executive Committee

(DEC). Additional staff are delegated by the department to serve on the CWC, DAC, and DEC. MoDNR is also responsible for developing and updating this Missouri Drought Mitigation and Response Plan. More information about the DAC and DEC is provided Section 6.3.3.

The MoDNR Water Protection Program, Financial Assistance Center, and regional offices provide many forms of assistance to public water systems suffering from drought including financial assistance, emergency waivers for construction authorization, and the sampling of alternative water supplies.

During emerging and current drought conditions, MoDNR also assists in coordinating state activation, alerts, and communications, including drought-related health advisories released through the Department of Public Health and Senior Services. The department continually monitors water resources to provide information on water availability and assist in coordinating with city and local officials on water conservation and restrictions in water use.

### *Missouri Department of Agriculture*

In emerging drought conditions, leadership from MDA coordinates closely with MoDNR to provide local data and information, and staff to serve on drought committees. The department works with the Missouri Farm Bureau and agricultural producers statewide to develop state requests for funding and assistance from USDA to local farmers impacted by drought conditions. MDA also administers the Hay Directory, an online marketplace that operates year-round and assists consumers in identifying available hay. The database is highly used, especially during drought conditions, and is available at: https://apps.mda.mo.gov/HayDirectory.

### *University of Missouri State Climatologist*

The Missouri State Climatologist monitors climate conditions statewide at the Missouri Climate Center. In close coordination with MoDNR, the climatologist provides current weather and drought information to drought committees, federal and state departments, and the public. During drought conditions, the Missouri Climate Center creates and publishes public information and presentations on drought conditions, climate outlook, and future projections. Weather and climate resources maintained by the Missouri Climate Center are available at: http://agebb.missouri.edu/weather/wealinks.htm or http://climate.missouri.edu.

### *Missouri Department of Public Safety*

The State Emergency Management Agency (SEMA) division of the Missouri Department of Public Safety coordinates state and federal resources as prescribed in the Emergency Operations Plan (EOP). Under drought conditions, SEMA coordinates drought-related press releases, and may be called upon to coordinate using the Missouri National Guard to set up water trailers, pipes, and pumps to serve local communities. If necessary, SEMA will develop a state request for a federal disaster declaration in a drought emergency. The SEMA State Volunteer Agency Liaison may help to organize volunteers in response to a drought disaster.

The state's Emergency Operations Center (EOC) operates at various levels of activation throughout a drought in accordance with four Crisis Action System (CAS) levels for assessment and response:

- CAS-1: Normal monitoring phase (Phase 1)
- CAS-2: DAC monitoring (Phase 2)
- CAS-3: Partial EOC activation recommended by DAC to the governor (Phase 3)
- CAS-4: Full EOC activation as recommended by DAC to the governor (Phase 4)

EOC staffing and operations at the four CAS levels are described in SEMA's EOP.

### 6.3.3 State Drought Response Committees and Impact Teams

#### *Drought Assessment Committee*

The DAC's responsibilities include issuing drought status updates in certain phases of a drought event and reviewing the recommendations of the CWC to designate drought levels for each county in Missouri. The DAC identifies resource deficiencies that may aggravate drought impacts and produces drought reports, as necessary. The DAC makes recommendations to the governor concerning state-level or regional response and recovery, along with coordinating with the governor and others as needed to develop drought legislation.

The DAC also makes recommendations, if needed, for activating impacts teams (ITs) that develop additional assessment information and identify emergency needs. Once activated, the DAC charges each IT with specific responsibilities and appoints a chair, vice-chair, and the membership of each IT. Not all teams will be needed in every drought situation. The DAC and ITs monitor and review potential impacts to agriculture, the economy, the environment, and natural resources. Information provided by the ITs and local water shortage teams helps the DAC evaluate how the Missouri Drought Mitigation and Response Plan is working and make recommendations to changes in state actions. The DAC is responsible for developing debriefs following a drought and revising the Missouri Drought Mitigation and Response Plan, as necessary, to better prepare for and respond to future drought events.

#### *Drought Executive Committee*

The governor activates the DEC independently or after reviewing a recommendation from the DAC. The DEC is composed of agency heads (or their designees) and other appropriate state representatives who have authority to commit agency staff and resources to respond to drought emergencies. DEC membership may include members of the DAC who have authority to act on behalf of the agency head in this capacity. The DEC is chaired by the director of MoDNR, or an appointee named by the governor, and meets on a regular basis for the purpose of administering and coordinating drought assistance in Missouri. The committee is charged with developing short- and long-term recommendations and options for the governor related to all aspects of drought response and management, including public health, safety, and welfare, and social, economic, and environmental concerns. The DEC recommendations and options are based upon data and information provided by the DAC.

The DEC membership consists of the governor's delegate; appointments from the Missouri Senate and House of Representatives; the state attorney general; the administrator of employment services; the chair of the Public Service Commission; SEMA; and the directors of the Missouri Departments of Agriculture, Conservation, Economic Development, Natural Resources, Public Health and Senior Services, and Public Safety. The DAC and/or DEC should seek assistance from the National Drought Mitigation Center for drought response implementation activities and intergovernmental coordination, as needed.

#### *Impact Teams*

An IT is composed of agency staff who are technical experts. The ITs gather, review, and provide detailed reports and analyses. ITs report their findings and recommendations to the DAC. The recommendations, reports, and findings from each IT should be reviewed by the DAC and MoDNR for potential updates to the Missouri Drought Mitigation and Response Plan. Findings from ITs should be communicated to the public and/or groups impacted by drought, as appropriate, to refine mitigation and response actions for effectiveness. It is recommended that appropriate state agencies keep updated listings of locations and sites that are environmentally, economically, or socially significant for timely access/reference by the DAC, ITs, and the public at large. ITs may support the following evaluations: agriculture, natural resources and

environmental, recreation, water supplies and wastewater, human health, social and communications, economic, and post-drought.

### *Local Water Shortage Teams*

A local team made up of major water users, government representatives, officials responsible for health and safety, and the local fire department should be established during drought events or in communities that regularly experience water shortages, especially during droughts. A local water shortage team can provide support for making and implementing difficult decisions during drought events, ensuring an appropriate and effective community response. The team should include persons who can help design and implement an effective public information and education program. Local water shortage teams should evaluate the vulnerability of their water supplies and the ability to meet demand if drought persists or worsens. Working with the DAC and ITs, local water shortage teams should determine the best mitigation and response actions based on the local conditions, water supplies, and water demands.

## 6.4 Local Drought Mitigation Capabilities

Local communities are responsible for enforcing state- and county-specific drought ordinances during drought conditions. Communities are encouraged to maintain communication and coordinate with MoDNR and other state departments throughout drought emergencies.

During the development of this plan, MoDNR contacted approximately 45 randomly selected small, medium, and large water utilities to better understand the type and level of drought planning being conducted at the local scale and to assess local drought mitigation capabilities and needs. Twenty-seven utilities (representing all sizes) responded to the survey, providing information regarding drought planning in their community. While only a small number of utilities across the state were surveyed, the results of the survey suggest that:

- Just over one-third of utilities maintain some form of a written drought plan.
- About one-third of the utilities provide water conservation tips to their customers, generally through a billing insert.
- About 40 percent of the utilities contacted have interconnections with neighboring utilities for use either as a primary or emergency backup source.
- About 40 percent of the utilities surveyed do not have access to backup water supplies.
- Only a small percentage of utilities use additional storage or backup wells as alternative sources of supply.
- About 30 percent of the utilities surveyed indicated a need for technical resources to assist in the drought planning and mitigation process. These materials may include references, training, and/or a template to assist in drought plan development.
- About 20 percent indicated that financial assistance would be necessary to develop a drought plan and implement measures to improve drought resiliency.

Local utilities indicated that technical assistance and funding are important gaps in drought planning capabilities. Funding opportunities that support drought mitigation would allow for increased drought resiliency and are essential for smaller utilities.

## 6.5 Drought Mitigation Funding

The ability to effectively develop and properly maintain drought mitigation and response is often contingent upon the availability of outside funding such as loans and grants. Drought funding for public water systems and other water users may be available through multiple federal and state sources. Federal and state funding sources are summarized in **Table 6-3**. Additional details on drinking water and water infrastructure funding can be found in the 2020 Missouri Water Resources Plan, Section 6, Drinking Water and Wastewater Funding Options, which includes information on loans and public finance sources such as public bond markets, bank programs, and bond funds.

**Table 6-3. Federal and State Drought Funding Sources**

| Program | Agency | Grant/Loan Funds Available | Description |
|---|---|---|---|
| U.S. Economic Development Administration (EDA) Grants | EDA | No limit (subject to federal appropriation) | EDA's Public Works Program and Economic Adjustment Assistance Program aid distressed communities by providing funding for existing physical infrastructure improvements and expansions. |
| Water Infrastructure Finance and Information Act (WIFIA) | U.S. Environmental Protection Agency (EPA) | Up to 49 percent of eligible project costs (minimum project size is $20 million for large communities and $5 million for small communities) | A federal credit program administered by EPA for eligible water and wastewater infrastructure projects, including drought prevention, reduction, and mitigation. |
| Section 502 Direct Loan Program | USDA Rural Development | Loans based on individual county mortgage limits | Loans are available for wells and water connections in rural communities. Availability is based on community income. |
| National Rural Water Association (NRWA) Revolving Loan Fund | USDA Rural Utilities Service | $100,000 or 75% of the total project | Provides loans for predevelopment costs associated with water and wastewater projects and for existing systems in need of small-scale capital improvements. |
| Emergency Community Water Assistance Grants | USDA Rural Development | Up to $100,000 or $1,000,000 depending on the type of project | Offers grants to rural areas and towns with populations of 10,000 or less to construct waterline extensions, repair breaks or leaks, address maintenance necessary to replenish the water supply, or construct a water source, intake, or treatment facility. |
| HMGP | FEMA | Variable | Provides funds to states, territories, tribal governments, and communities for hazard mitigation planning and the implementation of mitigation projects following a presidentially declared disaster event. |
| BRIC | FEMA | Variable | Provides support to states, local communities, tribes, and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards |

| Program | Agency | Grant/Loan Funds Available | Description |
|---|---|---|---|
| Planning Assistance to States | U.S. Army Corps of Engineers (USACE) | Variable – funding is 50% federal and 50% nonfederal | USACE can provide states, local governments, and other nonfederal entities assistance in the development of comprehensive plans for the development, utilization, and conservation of water resources. |
| Economic Development Assistance Program | Delta Regional Authority (DRA) | Variable | Southeastern Missouri is part of DRA. The flagship grant program provides funding for projects within the service region aimed at strengthening the Delta economy. |
| Drinking Water State Revolving Fund (DWSRF) | MoDNR | Congress appropriates funding for DWSRF that is then awarded to states by EPA based on results of the most recent Drinking Water Infrastructure Needs Survey and Assessment. Missouri provides a 20% match to federal grants | This program is a federal-state partnership aimed at ensuring that communities have safe drinking water by providing low-interest loans and grants to eligible recipients for drinking water infrastructure projects. |
| Missouri Multipurpose Water Resource Program Fund | MoDNR | Planning and feasibility studies are eligible for grants with cost share. Construction projects require remittance payments to the fund. | The program focuses on funding projects that cannot meet full funding needs through DWSRF or similar programs, particularly those that provide a long-term, reliable public water supply, treatment, or transmission facility in an area that exhibits significant need. |
| Soil and Water Conservation Cost-Share Practices | MoDNR | Variable | A portion of the Parks, Soils and Water Sales Tax is used for Missouri landowners to install soil and water conservation practices through the state cost-share program. These practices conserve soil, which consequently improves water quality and helps maintain water storage capacity by reducing sedimentation in rivers and streams. Practices aimed at irrigation management are also available. |
| Missouri Emergency Cost-Share Program | MoDNR | Variable | During previous drought events, an emergency cost-share program was enacted to provide additional funds for farmers and livestock producers. Projects which provided immediate benefits to livestock or crops and did not adversely affect public water supplies were eligible. |

## 6.6 References Cited

Missouri Department of Public Safety. 2018. *Missouri State Hazard Mitigation Plan*. State Emergency Management Agency. Available at: https://sema.dps.mo.gov/docs/programs/LRMF/mitigation/MO_Hazard_Mitigation_Plan2018.pdf

U.S. Department of Homeland Security. 2021. Biden Administration Commits Historic $3.46 Billion in Hazard Mitigation Funds to Reduce Effects of Climate Change. Available at: https://www.dhs.gov/news/2021/08/05/biden-administration-commits-historic-346-billion-hazard-mitigation-funds-reduce

# Section 7 Drought Mitigation and Response

## 7.1 Introduction

The Missouri Drought Mitigation and Response Plan identifies actions that can be taken to prepare for drought, lessening the impacts when drought occurs, and response strategies that provide for a measured response to worsening effects of drought. This section summarizes the most important local and state preparedness and response actions, identifies additional long-term actions, and presents a suggested framework for updating the plan. The entire portfolio of local and state preparedness and response actions and strategies are provided in Section 8.

This section also introduces recommended revisions to Missouri's phased drought response system. The recommended drought response system uses meteorological, agricultural, and hydrologic triggers in combination with the U.S. Drought Monitor (USDM) drought classifications to determine the appropriate phase of the drought response system that should be activated. Additional description of the recommended, phased response system is presented in **Appendix E.** Once a drought response phase has been declared, it allows the appropriate level of state and local government resources to be provided in support and relief of impacted citizens, businesses, farmers, and visitors.

### Overview of Section 7 Drought Mitigation and Response

This section identifies the recommended revisions to Missouri's phased drought response system. Potential mitigation and response actions, strategies, and resources that can be used during each phase to improve resiliency and/or reduce impact and damages are identified. Potential long-term alternative actions are also discussed along with a suggestion for plan maintenance and future updates. Subsections are organized as follows:

- Section 7.2 Drought Response System – recommends region-specific thresholds or triggers that can serve as guidelines for initiating the identified response actions and strategies, and leveraging available resources. The modifications to the existing Drought Response System will be potentially incorporated, pending further consideration by the Missouri Department of Natural Resources (MoDNR), other agencies involved in drought monitoring and response, and other stakeholders.
- Section 7.3 Drought Preparedness Actions, Strategies, and Resources – identifies the major actions that can be taken to prepare for drought. Predrought actions focus on monitoring (data and science), planning, policy and regulation, education and outreach, improving resilience through infrastructure projects, and funding.
- Section 7.4 Drought Response Actions, Strategies, and Resources – identifies the major response actions and strategies that can be taken while a drought is occurring.
- Section 7.5 Potential Long-Term Supplemental Actions – identifies potential mitigation actions that are programmatic or administrative, and require significant investment of time and effort along with coordination among departments and/or agencies across the state. These actions would be implemented prior to drought as part of a long-term initiative undertaken by the state.
- Section 7.6 Drought Plan Maintenance and Updates – details the suggested timeframe and activities for periodic updates to the Missouri Drought Mitigation and Response Plan.

## 7.2 Drought Response System

### 7.2.1 Missouri's Drought Response System

Historically, Missouri's Drought Response System has been divided into four phases to provide a measured response to worsening effects of drought, typically on a county-by-county basis. The four phases, which guide state-level government actions and responsibilities, include:

- **Phase 1 – Advisory Phase**: When climate and weather indicators signal that dry conditions and drought are possible in the coming months, the Climate and Weather Committee (CWC) notifies the MoDNR Department Director that conditions warrant activation of the Drought Assessment Committee (DAC).
- **Phase 2 – Drought Alert**: Activated when the Palmer Drought Severity Index (PDSI) reads -1.0 to -2.0 and streamflow, reservoir levels, and groundwater levels are below normal over a several-month period, and/or the CWC determines Phase 2 actions are required, then the MoDNR Department Director will request the Governor make a drought declaration for the counties or regions of the state experiencing drought conditions.
- **Phase 3 – Conservation Phase**: Activated when PDSI is between -2 and -4 and streamflow, reservoir levels, and groundwater levels continue to decline, forecasts indicate an extended period of below-normal precipitation, and/or the DAC determines Phase 3 conservation actions are required.
- **Phase 4 – Drought Emergency**: Activated when PDSI exceeds -4.0 and/or when the DAC determines Phase 4 activities are required. The MoDNR Department Director will request the Governor issue a drought emergency declaration.

While the PDSI, streamflow, and reservoir and groundwater levels have served as the triggers for moving from one drought phase to the next, in practice, MoDNR has more recently considered other indices to monitor drought conditions across the state. The agency has also considered short-term weather forecasts for signs of possible emerging drought.

During development of this plan, the Drought Response System originally detailed in the 2002 Missouri Drought Plan was reviewed. Minor revisions to the Drought Response System have been proposed to better align with the USDM and allow for consideration of additional indices applicable to meteorological, hydrologic, and agricultural indicators, and to include indices that help identify rapidly changing conditions and the possible emergence of a flash drought. The proposed updates to the Drought Response System are detailed in **Appendix E** and are summarized below.

### 7.2.2 Overview of the Proposed Drought Response System

The proposed Drought Response System maintains the same advisory, alert, conservation, and emergency phases but adds a new "incipient" phase, which recognizes the threat of a drought demonstrated by the drought indices and indicators. The incipient phase is recognized as phase 1, and the alert, conservation, and emergency phases remain as phases 2, 3, and 4, respectively. The advisory phase, phase 0, represents the lack of drought conditions. Routine monitoring of drought indices and indicators occurs during the advisory phase, and predrought mitigation actions and strategies are developed, considered, and implemented to lessen impacts should a drought occur.

The proposed primary and secondary indices and indicators that should be considered on a weekly basis to determine movement from one drought phase to another are listed in Table 7-1. Although movement from one drought phase to another may be declared based on any one of the indices or indicators, the five primary indices and indicators are generally intended to be used in concert with each other using a "convergence of

evidence" approach. The proposed numeric values associated with each index or indicator and phase are presented in **Appendix E**.

**Table 7-1. Proposed Response Plan Indices and Indicators**

| Primary Indices and Indicators | Drought Type | Description |
|---|---|---|
| U.S. Drought Monitor (USDM) | Comprehensive | Uses a variety of drought, climatological, hydrological, soil moisture, and other indicators. |
| Standard Precipitation Index (SPI) | Meteorological | Compares observed precipitation over 1- to 24-month periods with long-term averages for the same period. |
| Palmer Drought Severity Index (PDSI) | Agricultural | Incorporates monthly temperature and precipitation along with water-holding capacity of soils. Includes memory from past months. |
| Crop Moisture Index (CMI) | Agricultural | Uses the difference between potential evapotranspiration and moisture to indicate short-term moisture supply for crop producing regions. |
| Streamflow (28-day) | Hydrologic | Compares observed streamflow over a 28-day period with long-term averages for the same period. |
| **Secondary Indices and Indicators** | **Drought Type** | **Description** |
| Evaporative Drought Demand Index (EDDI) | Flash | Examines how anomalous the atmospheric evaporative demand (the thirst of the atmosphere) is for a given location over 1 week and 4 weeks. |
| QuickDRI | Flash | Represents a drought alarm indicator of emerging or rapidly changing drought conditions. |

The major actions taken by the CWC, the DAC, the Drought Executive Committee (DEC), and others under the proposed drought response system phases are summarized below. More detailed roles and responsibilities are presented in **Appendix E** for each phase.

- **Phase 0 – Advisory Phase**: MoDNR, in consultation with the State Climatologist, conducts weekly reviews of the drought indices and indicators, and other climate conditions and forecasts. The advisory phase continues if indices and indicators show no evidence of emerging drought conditions.

- **Phase 1 – Incipient Phase**: When climate forecasts and primary indices and indicators signal that dry conditions are possible in the coming months, MoDNR activates the CWC and notifies the MoDNR Department Director that a worsening of conditions may warrant activation of the DAC. Emerging or rapidly changing conditions, as observed using the secondary indices, can also trigger movement into this phase and the potential activation of the DAC at the discretion of the director. Incipient phase conditions correlate to the USDM D0 category representing abnormally dry conditions. Monitoring and consideration of the indices and indicators should accelerate if conditions approach or enter the alert phase.

- **Phase 2 – Alert Phase**: The alert phase is declared when the CWC recognizes worsening but still moderate drought conditions. The MoDNR Department Director requests the Governor make a drought declaration for the counties or regions of the state experiencing alert phase drought conditions, which correlate to the USDM D1 category representing moderate drought. The declaration of a drought alert by the Governor directs state agencies to work together in providing as many resources and as much assistance as possible to impacted communities. The DAC is

activated and populated by representatives from key state and federal agencies and supported by input from stakeholders representing impacted counties or regions. Impact teams (ITs) may be formed to interact with key stakeholders and assist in data gathering and review. ITs may be asked to conduct analyses and report on conditions in specific counties or regions.

- **Phase 3 – Conservation Phase**: The conservation phase is declared when the CWC recognizes worsening drought conditions and forecasts indicate an extended period of below-normal precipitation, suggesting actions to conserve water are warranted. The MoDNR Department Director requests the Governor make a drought declaration for the counties or regions of the state experiencing conservation phase drought conditions, which correlate to the USDM D2 category representing severe drought. The DAC empowers the ITs to encourage impacted areas to implement water conservation and take other plan-recommended actions and strategies to reduce demand and conserve supplies.
- **Phase 4 – Drought Emergency**: The emergency phase is declared when the drought conditions enter the USDM D3 (extreme) and D4 (exceptional) categories and forecasts indicate continued below-normal precipitation, suggesting emergency actions are necessary to support essential water uses and protect public health. The MoDNR Department Director may request the Governor make a drought declaration for the counties or regions of the state experiencing emergency phase conditions. The governor activates the DEC independently or upon recommendation of the DAC. The Missouri Department of Agriculture may draft an executive order for an agricultural disaster declaration and a Health and Public Safety Declaration may be drafted by the Missouri Emergency Management Association.

## 7.3 Drought Preparedness Actions, Strategies, and Resources

This section focuses on the major actions that can be taken to prepare for drought. These preparedness actions are intended to occur as soon as possible because of the time needed for implementation and for benefits to be realized during a drought event. For example, enhancing water supply storage at existing reservoirs takes months to years for engineering studies, design, permitting, and implementation, making it an impractical choice to begin implementing as drought conditions begin.

The actions that help prepare for drought are organized by category and subcategory. The categories (**in bold**) and subcategories (in parentheses) include:

- **Supply** (Increase Storage, Alternate Sources, Planning, Assistance, Increase Supply, and Water Efficiency)
- **Demand** (Assistance, Monitoring, and Water Efficiency)
- **Education/Data** (Monitoring, Planning, and Policy)
- **Education/Outreach** (Planning, Assistance, and Water Efficiency)

A comprehensive matrix of all drought preparedness and response actions is presented in Section 8. The major recommended actions presented below are represented by one or more numbered actions in the matrix of actions of Section 8. The number(s) in parentheses following each major recommended action correspond to the numbered actions in the matrix.

### *Supply – Increase Storage*

An increase in the severity and frequency of extreme weather events is an expected result of future climate change. Communities are increasingly evaluating strategies that enhance resiliency to both flooding and drought. Strategies such as the diversion and storage of floodwater, and managed aquifer recharge, both

reduce impacts of flooding and provide storage that can be used as a source of supply during drought. Increasing storage capacity is generally more cost-effective than building a new supply source.

Major recommended actions associated with this subcategory include:

- Enhance storage at existing reservoirs and farm ponds (17 and 112).
- Implement aquifer storage and recovery (ASR) (18).
- Explore technologies for water supply banking, floodwater diversion storage, and managed aquifer recharge (13).
- Reduce sedimentation and loss of storage capacity in ponds and reservoirs through creation of wetlands, cover crops, and other means of minimizing erosion (15).

### *Supply – Alternate Sources*

Water sources that have not typically been used for agriculture, industrial, or municipal use may be brought into service during a drought event to provide additional supply. These alternate sources may require additional treatment, blending, or other actions that necessitate prior analysis and/or construction of infrastructure to be available for implementation in a drought event. Water quality and cost-effectiveness are key considerations for these mitigation actions.

Major recommended actions associated with this subcategory include:

- Explore the feasibility of using inactive groundwater wells or surface water intakes if existing supplies become limited (1).
- Where existing water supplies are limited, add additional treatment and blend highly mineralized or lower-quality groundwater with existing, higher-quality water (7).
- Build a water system interconnection to one or more nearby water systems or a pipeline to a new raw water supply (2 and 5).

### *Supply – Planning*

Proactive planning regarding supply options should occur well before a drought event begins. Coordination between water utilities to identify opportunities for interconnections between systems, proper drought response planning, water transfers, and identifying deficiencies in operational capabilities of a utility/water system need to be addressed and given adequate time for changes to be implemented.

Major recommended actions associated with this subcategory include:

- Encourage or require communities to include drought mitigation and response elements in their local emergency operations plans (31).
- Promote, support, and fund water supply regionalization and public/private partnerships to augment or replace local, limited water supplies (28 and 32).
- Conduct a statewide survey of water utility interconnections (34).

### *Supply – Assistance*

State agencies can be instrumental in providing much-needed technical assistance in identifying and assessing supply option strategies, especially for small communities. Water utilities that serve small communities or rural areas typically lack the resources necessary for planning and funding supply option studies or creating alternative water supplies.

Major recommended actions associated with this subcategory include:

- Provide technical and planning assistance to identify alternative water supplies (9).
- Provide technical assistance to evaluate a reservoir's capacity to meet current and projected water supply needs during drought (11). See **Appendix D** for an example of how models can be used to determine reservoir safe yield and evaluate supply and demand-side strategies to improve resilience to drought.
- Fund water system improvements for drought mitigation and resiliency (12).

### *Supply – Increase Supply*

New supply sources or adjustments to how existing supply sources are used can increase the available quantity of water for municipal and industrial use or for agricultural producers. These actions are typically more costly than increasing storage but allow for immediate use once completed, whereas increased storage usually has a longer timeframe for implementation.

Major recommended actions associated with this subcategory include:

- Improve the reliability of water supplies for livestock and pasture production during periods of drought (19).
- Construct floating or multilevel intake structures in rivers or reservoirs (21).
- Develop reclaimed (recycled) water systems for nonpotable uses, such as landscape irrigation, nonfood crop irrigation, cooling towers, and vehicle washing (23).
- Change state regulations to allow the discharge of treated wastewater to water supply streams or reservoirs to supplement sources of supply (indirect potable reuse) (25).
- Reallocate water supply storage in federal reservoirs where additional storage could be allocated for municipal and industrial supply (26).

### *Supply – Water Efficiency*

Improving water efficiency through reductions in water loss at treatment plants, pump stations, and other common points of leaks can increase available supply without new sources of water. Likewise, exploring water reuse options can increase available water supply. However, the volume of water available from water efficiency measures can be limited in times of drought if water use is reduced, since there is less water available to save and reuse for other purposes.

Major recommended actions associated with this subcategory include:

- Promote rainwater harvesting methods, such as cisterns or rain barrels and cooling condensate capture, for nonpotable uses such as landscape irrigation (36).
- Explore beneficial uses for flushed water, such as irrigation, construction, fire-fighting storage, or other nondrinking water uses (37).

### *Demand – Assistance*

Small water providers/communities, industrial water users, and commercial water users could benefit from assistance with water audits and leak detection to reduce water loss, which in turn lowers demand. Providing technical and/or financial assistance to these users can save significant quantities of water, which increases the amount available to other users, especially during drought.

Major recommended actions associated with this subcategory include:

- Provide grants, technical assistance, and/or planning assistance for improving leak control efforts and metering of all customers (39).
- Conduct water audits or provide water audit training to industrial and commercial users, or to water utility/municipal staff so they can provide water audits to their customers (40).

### *Demand – Monitoring*

Monitoring soil moisture levels can give more advanced warning to farmers that local conditions are deteriorating and that supplemental irrigation is required. Increasing soil moisture retention can help reduce the demand needed for supplemental irrigation since the soil is holding moisture for longer.

Major recommended action associated with this subcategory include:

- The Missouri Department of Agriculture should provide information on soil moisture monitoring and measurements and methods to improve soil moisture retention, such as aeration and mulching (41).

### *Demand – Water Efficiency*

Improving water efficiency on the customer side is a key component of demand management strategies. Water efficiency improvements can allow utilities to delay or potentially eliminate the need to develop or access additional water supply sources to meet the needs of their customers. Reducing leaks and the use of high-efficiency fixtures can save significant quantities of water at a relatively low cost. Repairing leaks for utilities is only financially beneficial when the cost of water lost is higher than the cost of repair. However, in times of drought, the value of water increases even if the cost remains the same, so repairing leaks that are otherwise not cost-effective may prove worthwhile, especially if supplies are beginning to run low.

Major recommended actions associated with this subcategory include:

- Conduct water audits of agricultural irrigation systems and implement measures to improve water use efficiency (43).
- Implement and maintain a water efficiency and water loss control program. Water utilities should routinely conduct leak detection, fix leaks, replace old infrastructure, limit process water losses, and track nonrevenue water loss (53).
- Install advanced metering infrastructure systems with smart meters, communication networks, and data management systems that provide a customer portal with potential leak alerts and provide system operators with potential system leak alerts (55).
- Provide incentives for residential customers to improve water use efficiency in the home. Set up rebate, distribution, or installation programs for WaterSense or Energy Star-certified high-efficiency toilets, clothes washers, shower heads, water heaters, irrigation technology, and other water-saving appliances (63).
- Provide incentives for commercial customers to improve water use efficiency in businesses. Set up rebate, distribution, or installation programs for WaterSense or Energy Star-certified high-efficiency urinals, commercial dishwasher systems or prerinse spray valves, and ice machines or similar appliances (66).

### *Education/Data – Monitoring*

Monitoring a variety of weather and climate data tools can help provide earlier warning of drought events and allow proper planning, resources, and guidance to be put into place before a drought occurs. Developing standardized monitoring and reporting tools helps to quantify the impacts of drought in a consistent manner, which can improve drought response and aid in evaluating which mitigation and response actions are most beneficial. Increased monitoring of weather and climate can benefit other areas of research and provide long-term benefits to the state in other ways (crop research, energy consumption, water demand forecasting, etc.).

Major recommended actions associated with this subcategory include:

- Increase weather and climate monitoring and expand manual/automated data networks for precipitation, hydrology, and soil moisture/infiltration to support drought assessment (70).
- Monitor the Drought Early Warning System (DEWS) for the two regions that overlap with Missouri (Missouri River Basin and Midwest DEWS) to stay aware of changing conditions to help predict drought and begin mitigation actions accordingly (77).
- Make use of more recent and experimental drought forecasting tools (4-Week EDDI Forecast, QuickDRI, and Potential Flash Drought) on the Drought.gov website to monitor when conditions favor upcoming droughts (79).

### *Education/Data – Planning*

Collecting and analyzing data related to drought impacts and the effectiveness of drought response actions can improve drought mitigation and response during drought events by identifying which actions work and the magnitude of the impact they provide.

Major recommended actions associated with this subcategory include:

- Disseminate information from drought forecasting tools (such as the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center's Monthly and Seasonal Drought Outlooks, 4-Week Evaporative Demand Drought Index Forecast, and Potential Flash Drought) to agricultural producers, livestock producers, state agencies, local governments, and other stakeholders when indications of future drought are likely (83).
- After a drought event, evaluate the effectiveness of mitigation efforts undertaken prior to the drought and any possible adjustments that might improve the effectiveness of the mitigation action for the next drought event (85).
- Perform data collection and analysis of the impacts on private (domestic) water supplies from drought. Determine standardized method of analysis to ensure information is useful, can be analyzed over a period of several years, and assessed over different drought events (87).

### *Education/Data – Policy*

Financial and institutional support for public research on drought tolerant agricultural species of crops would benefit farmers across the state and possibly the nation. Advances in drought agriculture could potentially reduce impacts of droughts, reduce water demands, and/or provide farmers with more flexibility in crop selection and land management.

The major recommended action associated with this subcategory is:

- The Missouri Department of Agriculture and state universities should support agricultural research of drought tolerant species (88).

### *Education/Outreach – Planning*

Providing educational support and guidance related to drought planning can help agricultural producers, businesses, industry, and municipal water providers better prepare for drought. Identifying trigger points and proper response actions can extend water supplies and reduce impacts from drought if water users know how to respond appropriately.

Major recommended actions associated with this subcategory include:

- Educate agricultural producers on production modifications and technical assistance available to lessen drought impacts (93).
- Continue to maintain, expand, and promote the use of the MoDNR drought website (94).
- Establish statewide water conservation guidelines for drought conditions (95). **Appendix F** includes water conservation tips and water saving recommendations for various stages of drought for residential, institutional, and industrial water users.
- Encourage local-level drought planning and increase community/local-level drought planning assistance. Local communities should identify leaders for drought response actions and coordination (98). The example provided in **Appendix G** can be used as a guide for developing a local drought plan.

### *Education/Outreach – Assistance*

Outreach and assistance efforts already exist in some form and have been used in past drought events to increase the awareness of resources and potential mitigation actions available to farmers and livestock producers. These efforts should be continued and expanded where possible.

Major recommended actions associated with this subcategory include:

- The Department of Agriculture, state universities, and rural water associations should conduct workshops on crop survival and livestock management during drought (89).
- University of Missouri Extension and other state universities should conduct routine outreach with the agriculture sector to build awareness of the drought planning and response information and guides available to them through University of Missouri Extension and other sources (90).

### *Education/Outreach – Water Efficiency*

Providing education and outreach to customers regarding water efficiency is essential for water savings to be realized. Without the proper knowledge, the water savings will not occur. Water providers should work to educate their customers and collaborate with other utilities to ensure consistent water efficiency messaging. Demonstrating relative simplicity of water efficiency measures and the potential cost savings to customers are the two main components of most education and outreach efforts.

Major recommended actions associated with this subcategory include:

- Offer water efficiency/water conservation workshops covering water-saving tips for customers (102).
- Encourage local agencies to collaborate with neighboring utilities to implement the same water use restrictions and announce the end-of-drought emergency and water restrictions (105).
- Collaborate with major water users supplied by a municipal source to identify water-saving measures they can take without harming their business. Provide commercial, industrial, and institutional water audits with recommendations for cost-effective water efficiency improvements (107).

## 7.4 Drought Response Actions, Strategies, and Resources

This section focuses on actions that can be taken during the incipient, alert, conservation and emergency phases (phases 1, 2, 3, and 4, respectively) of drought. These actions are responsive in nature and depend on the specific conditions and challenges presented by each drought. For example, a flash drought impacting agricultural producers requires different response actions than a long-term hydrologic drought that impacts multiple sectors.

The major recommended drought response actions are organized by category and subcategory. The categories (**in bold**) and subcategories (in parentheses) include:

- **Supply** (Increase Storage, Alternate Sources, Increase Supply, and Water Efficiency)
- **Demand** (Policy and Water Efficiency)
- **Other** (Policy)

A comprehensive matrix of all drought preparedness and response actions is presented in Section 8. The major recommended actions presented below are represented by one or more numbered actions in the matrix of actions of Section 8. The number(s) in parentheses following each major recommended action correspond to the numbered actions in the matrix.

### *Supply – Increase Storage*

The ability to increase storage during a drought event can reduce impacts on farmers and livestock producers but is only beneficial if additional water is available to fill the reservoir or pond being improved. Emergency cost-sharing programs enacted during past drought events have increased storage of private ponds used for agriculture to reduce impacts to farmers and livestock producers. Alternatively, adjusting discharges from reservoirs can increase available storage meant for municipal and industrial or agricultural use.

> Major recommended actions associated with this subcategory include:
>
> - Request temporary authorization from regulatory agencies to reduce water releases from reservoirs, in accordance with an agreed upon schedule of reductions within a formal drought contingency plan (14).
> - Remove sediment from ponds used to supply water to farms and/or livestock (112).

### *Supply – Alternate Sources*

Alternate sources can be utilized if the available water supply diminishes to a point of concern for a utility or agricultural producer. Infrastructure must already be in place for alternate sources to be accessed or water must be hauled to the needed location. Hauling water to municipal customers is typically an option of last resort and should include water rationing to ensure adequate supplies for all residents. See **Appendix H** for details on water use classes and essential uses of water during times of drought.

> Major recommended actions associated with this subcategory include:
>
> - Use an existing, emergency water system interconnection to a neighboring water system (3).
> - Use certified potable water hauling trucks to deliver water to communities with insufficient supply and in immediate need in an emergency drought situation (4)
> - Allow water to be pumped from Missouri Department of Conservation areas and state parks to family-owned farms. Water is meant to be used for livestock needs only (115).

### *Supply – Increase Supply*

Supply can be increased during times of drought by augmenting existing supplies with other sources or increasing supply capacity of groundwater wells. Emergency cost-sharing programs enacted during past drought events have provided funds for groundwater well improvements to reduce the impacts to farmers and livestock producers. However, groundwater resources should be used in a responsible manner to ensure long-term availability, and surface water resources used to increase supply must not be diminished to the point of reducing beneficial uses of that water for other uses and/or purposes within the watershed.

Major recommended actions associated with this subcategory include:

- Drill new groundwater wells, deepen existing wells, and/or lower well pumps (20 and 22).
- Augment reservoir inflows by pumping from nearby streams outside of the reservoir's drainage area, especially during high streamflow, to keep water levels in reservoirs near full (24).
-

### *Demand – Policy*

Water utilities typically give large commercial water users reduced rates for water to incentivize development within the utility's service area and to provide net economic benefit since water is used in the process of producing goods and services by these commercial customers. However, reduced water rates during times of drought should be discouraged, and suspended when contractually possible, to reduce water demands and ensure equity in available supplies for all customers.

The major recommended action associated with this subcategory is:

- Temporarily suspend a reduced water rate given to large water users to discourage excessive water use (116).

### *Demand – Water Efficiency*

Demand can be artificially suppressed by utilities and municipalities during times of drought using monetary measures that penalize excess water use. Changes to water rates, penalties for exceeding certain thresholds, or use of municipal ordinances to restrict water use are all effective actions that have been proven across the country to reduce water use. However, customers that can afford higher costs for water do not always reduce water consumption and water rate increases can create resentment from the public if some customers do not reduce consumption and/or the increase in rates is significant. Minimum allotments should be provided at a base charge that ensure enough water for daily necessities (e.g., health and hygiene).

Major recommended actions associated with this subcategory include:

- Establish water rate drought surcharges on water use during drought conditions (45).
- Implement mandatory restrictions on water use. As a component of this, provide tips on reducing water use and make use of enforceable penalties for customers who do not restrict non-essential or prohibited water use (47).

### *Other – Policy*

Changes to standard policies regarding transportation of hay, cover crop requirements, and haying and grazing in otherwise restricted areas can help alleviate some of the burden for livestock producers during drought by increasing the supply of and access to hay. These types of policy actions have been used in previous drought events and should be continued to be used in future drought events when applicable.

Major recommended actions associated with this subcategory include:

- Grant waivers that eliminate the fee for oversize loads so that farmers can transport large loads of hay. Also allows for transportation of oversized/overweight loads at night and during holidays (109).
- Allow haying of cover crops to provide needed forage and waive requirement that the production crop must be a minimum of two crop rotations (110).
- Soil and water districts can grant variances that allow grazing in livestock exclusion areas (113).
- The Natural Resource Conservation Service (NRCS) can grant a special allowance to cut hay on the grassy areas within the wetland easements (114).

## 7.5 Potential Long-Term Supplemental Actions

Several of the potential drought mitigation and response actions are long-term initiatives that would require significant amounts of time, effort, money, and/or changes to legislation to implement. These actions would not be appropriate to initiate at the beginning or during a drought since they would not be implemented in time to provide meaningful impact but would nonetheless improve Missouri's ability to mitigate and respond to future drought events. Some of these actions are already being performed but should either be increased or are significant enough that promoting their continued use is warranted. The potential long-term actions include:

- State legislation creating tax credit incentives for installation of high-efficiency appliances and fixtures can help increase the rate at which Missouri residents implement these efficiency improvements in their homes. Improving water efficiency can reduce demands and provide resiliency in future droughts. State tax incentives, low-interest loans, or grants could be provided for reclaimed (recycled) water systems for nonpotable uses which would increase the existing supply available to be used for potable demands.
- State regulations should be reviewed for potential changes allowing indirect potable reuse, which uses treated wastewater flows to supplement existing supplies. Indirect potable reuse uses an environmental buffer, such as a lake or river, before the water is treated at a water treatment plant to meet drinking water standards. Although current regulations prohibit the deliberate augmentation of a drinking water source with treated water, this supply strategy is effectively and safely used in other states across the country. Indirect potable reuse can benefit all water sources but especially those that may be limited during drought.
- As suggested by the state climatologist and presented in Section 2.2.2, crop reporting districts should be used for climate analysis, drought monitoring, and response planning instead of climate divisions. The nine crop reporting districts in Missouri offer more detailed spatial resolution than the six climate divisions and better represent the variation in climate across the state than climate divisions. However, using crop reporting districts for collecting climate data would take coordination with the NOAA National Centers for Environmental Information and could present challenges with data interoperability.
- Encouraging local drought planning efforts and providing state funding, when available and appropriate, should be considered to improve the overall level of drought resiliency for Missouri. Drought mitigation plans could be a state requirement for local emergency operations plans and would require local communities to give more consideration to drought planning. State-level promotion, support, and funding for water supply regionalization should continue to occur to increase institutional support and funding opportunities available for such efforts.

- Many planning and water conservation activities take years to implement and/or gain traction with the public, so starting these actions as soon as possible will produce the best outcomes during future drought events. New technology and social media will allow greater communication between impacted stakeholders and government agencies. Both state and local government should maximize the potential positive benefits these can produce in planning, mitigating, and responding to drought. Continuing to maintain and promote the MoDNR drought website, along with supporting the use of drought reporting tools like the Condition Monitoring Observer Reports, will provide more resources for the public and increase the planning ability of state and local agencies.

## 7.6 Drought Plan Maintenance and Updates

The Missouri Drought Mitigation and Response Plan should be updated periodically because of changing climate conditions, changes to state agency capabilities and/or responsibilities, changes in drought monitoring and assessment capabilities, and other factors. The following elements of the plan should be revisited every 3 to 5 years, and updated when appropriate:

- The list of local and state preparedness and response actions and strategies provided in Section 8 (and maintained as a downloadable actions matrix on MoDNR's Drought web page) should be reviewed and updated.
    - Following drought events, mitigation and response actions should be reviewed. Actions that were effective should be retained. Actions that were not effective at mitigating impacts should be revised or removed.
    - Actions and strategies that were not previously identified but have been proven successful elsewhere, or show promise for use in Missouri, should be considered and added.
    - Progress toward implementation of each action should be tracked. Additional fields can be added to the actions matrix (spreadsheet version) to track implementation status, success, or setbacks.
    - The "Where can I find more information" field of the actions matrix should be reviewed and updated to ensure web links are current and active. New sources of information for each action can be added, as appropriate.
    - The implementing agencies associated with each action should be reviewed and updated as needed.
- The potential long-term, supplemental actions presented in Section 7.5 should be reviewed. Progress toward implementation of these actions should be tracked.
- The drought response system should be reviewed. Revisions should be considered if new drought indices are developed that improve drought monitoring. Revisions to the indices and triggers should be made if their application proves cumbersome, overly subjective, or ineffective.

The plan should receive major updates every 10 years. In addition to the more frequent updated mentioned above, major updates should include:

- A review and refresh of the drought planning goals.
- An update of drought impacts, based on droughts that have impacted Missouri in the last 10 years.
- An updated assessment of resilience, based on changes in water use, new interconnections, and other factors.

- An updated assessment on economic impacts, based on droughts that have impacted Missouri in the last 10 years.
- Review and consideration of current global climate models to evaluate if potential changes to Missouri's climate is changing the likelihood and severity of future droughts.
- An updated assessment of susceptibility to drought based on assessment of projected demands and available supply.
- An updated analysis of regional differences in drought vulnerability, based on updated assessment of likelihood, susceptibility, impact, and resilience.

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# Section 8 Matrix of Drought Actions

## 8.1 Introduction

A key component of the Missouri Drought Mitigation and Response Plan is a matrix of drought mitigation actions and strategies. The matrix of over 100 actions and strategies is intended to aid state, federal, and local government officials; commercial, industrial, and private water users; and public and private water suppliers in both planning for and responding to drought events in Missouri. Some of the actions and strategies presented in the matrix have already been implemented and have been proven to be useful in mitigating impacts. Others should be considered for implementation prior to or in response to future droughts.

The actions were developed by water resources engineers and scientists with input from individuals representing local, state, and federal agencies involved in water planning, climatology, agriculture, recreation, tourism, and emergency management. Numerous sources were used to supplement and refine the matrix of recommended actions, including the 2002 Missouri Drought Plan; the 2018 (Missouri) Drought Response Final Report; drought plans from Colorado, Illinois, Kansas, Nebraska, South Dakota and Washington; the National Drought Mitigation Center at the University of Nebraska; the National Integrated Drought Information System; and the 2021–2024 Midwest and 2021–2023 Missouri River Basin Drought Early Warning System Strategic Action Plans.

## 8.2 Using the Matrix of Drought Actions

The matrix of drought actions is intended to be a living document, updated every 3 to 5 years, or sooner if a drought occurs. The matrix exists as both a "static" table, included in this plan as **Table 8-1**, and a Microsoft Excel spreadsheet that can be downloaded from the Missouri Department of Natural Resources (MoDNR) drought website at https://dnr.mo.gov/water/hows-water/state-water/drought. In spreadsheet form, the matrix can be filtered and sorted to more easily identify actions and strategies that (1) are most relevant to a specific water use sector; (2) are associated with a primary plan goal; (3) improve resilience, reduce susceptibility, or reduce impact; (4) are most applicable in a certain crop reporting district; or (5) are most applicable to a particular phase of drought.

Each action in the matrix is categorized and characterized by the following fields:

| | |
|---|---|
| **Number** | Each action is assigned a number. In **Table 8-1**, the number is included in parentheses following the description of the action. In the spreadsheet version, the number is listed in the first column. |
| **Category** | Actions are categorized one of five primary ways: **demand, education – data, education – outreach, supply,** or **other**. |
| **Subcategory** | Actions are further categorized into one of eight subcategories: **alternate sources, assistance, increase storage, increase supply, monitoring, planning, policy,** or **water efficiency.** |
| **Primary Sector** | The primary water use sector in which the action is most directly applicable. Sectors include **agriculture, energy, environment, industrial, municipal, tourism,** or **all**. |

The "**Why is this action needed?**" field summarizes the potential benefits of each action, and where appropriate, recognizes impediments to implementation or possible limitations to the action's effectiveness. For many of the actions, useful web links and/or references to specific sections of this plan or the Missouri

Water Resources Plan 2020 Update are included in the "**Where can I find more information**" field. These links and references provide additional details about the actions, including information on their potential effectiveness.

Although each action may support more than one of the eight drought management goals that were introduced in Section 6, a primary goal is assigned to each action. Each action is also characterized as to whether it improves resilience, reduces impacts and damages, and reduces susceptibility, as defined and discussed in Sections 3, 4, and 5, respectively. Recognizing that some actions are likely to be more effective or easier to implement in certain parts of the state compared to others, the applicability to each of the nine crop reporting districts is identified.

The expected stakeholders for each action are listed. Stakeholders are the groups, agencies, departments, associations, and other entities that may play a role in implementing the suggested drought mitigation action or strategy. No assignment of responsibility is intended with the matrix, rather it is a guide for which stakeholders would most likely be associated with a given drought mitigation action or strategy.

Finally, the drought phase to which each strategy most directly applies is noted. Since most actions could apply to multiple drought phases, the earliest drought phase that the action should be considered is generally used. Recognizing the importance of predrought planning, 70 percent of the actions included the matrix are recommended for implementation in the advisory phase (phase 0) of the proposed Drought Response System.

**Table 8-1** is organized first by category, then by subcategory, and then by the applicable drought phase. All **supply** category actions are listed first, followed by **education – outreach, education – data,** and then **demand** actions. The downloadable spreadsheet of actions can be filtered and sorted using any one of the fields.

**Table 8-1. Matrix of Drought Actions**

| | |
|---|---|
| **Category** | Supply |
| **Subcategory** | Alternate Sources |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Consider use of inactive groundwater wells or surface water intakes if existing supplies become limited. Prior to drought, investigate the feasibility of using these inactive sources. (1) | All | Inactive wells or surface water intakes can sometimes serve as an additional source of supply if primary sources become limited during drought. | | 3-Enhancing Resiliency | Improve Resilience<br><br>Reduce Impact/ Damages | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Missouri Department of Natural Resources |
| Build a water system interconnection to connect to one or more nearby water systems. (2) | Municipal | Interconnections to neighboring water systems can provide an additional source or water if the primary source is unable to meet demands during drought. | Section 3 of the Missouri Drought Mitigation and Response Plan | 3-Enhancing Resiliency | Improve Resilience<br><br>Reduce Impact/ Damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central<br>Central<br>East Central | Missouri Department of Natural Resources, Department of Environmental Quality<br><br>U.S. Department of Agriculture, Rural Development Program<br><br>Local Groups and Entities (Cities, Counties, Utilities) |
| Build a pipeline to a new or existing water supply. (5) | Municipal | Water conveyance infrastructure can help communities connect to an alternate source of supply that can be used routinely, or when existing supplies are impacted by drought. | | 3-Enhancing Resiliency | Improve Resilience<br><br>Reduce Impact/ Damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions<br><br>Missouri Department of Natural Resources |

| | |
|---|---|
| **Category** | Supply |
| **Subcategory** | Alternate Sources |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Where existing water supplies are limited, add additional treatment and blend highly mineralized or lower quality groundwater with existing, higher quality water. (7) | Municipal | Within portions of Missouri, especially those in the northern or western areas of the state where groundwater resources are highly mineralized, blending and treatment could be used to augment existing, but limited supplies. Membrane technologies such as reverse osmosis and nanofiltration can be used to remove minerals from highly mineralized water. High energy costs, relative to traditional treatment processes, and the discharge and disposal of concentrate must be considered. | **The U.S. Bureau of Reclamation issued a report evaluating reverse osmosis and nanofiltration to treat brackish groundwater in Texas. The report can be found at:** https://www.usbr.gov/gp/otao/treating_brackish_groundwater_texas.pdf | 3-Enhancing Resiliency | Improve Resilience<br><br>Reduce Impact/ Damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions<br><br>Regulatory Agencies |
| Explore the potential for direct potable reuse. (8) | Municipal | Potable reuse may be an option to consider only when existing supplies are limited, the cost of importing water is prohibitive, and opportunities for non-potable reuse are limited. While there are no federal or state regulations governing potable reuse, The Safe Drinking Water Act and Clean Water Act provide a foundation for which states can further develop and support potable reuse as they deem appropriate. | **EPA's Potable Reuse Compendium:** https://www.epa.gov/sites/default/files/2018-01/documents/potablereusecompendium_3.pdf | 3-Enhancing Resiliency | Improve Resilience<br><br>Reduce Impact/ Damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions<br><br>Regulatory Agencies |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Alternate Sources | | | | | | |
| Applicable Drought Phase | Phase 2 – Drought Alert | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Engage in bulk water purchases or leases from other municipalities, regional water suppliers, or other entities that have excess water supply available to sell. (6) | Municipal | Bulk water purchases or leases can be used to augment an existing supply, especially in times of drought, if the infrastructure is in place to deliver the water to the purchasing utility or entity. The purchase of a new contract in a USACE reservoir is another potential alternate supply source for municipalities. | | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce Impact/Damage<br><br>Reduce Susceptibility | Northwest<br>North Central<br>Northeast<br>West Central<br>Central<br>East Central<br>Southeast | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions |
| Allow water to be pumped from MDC areas and state parks to family-owned farms. Water is meant to be used for livestock needs only. Farmers would need to provide their own pumping and/or hauling equipment. (115) | Agriculture | Additional supply that would not normally be available to farmers that can help sustain herds through a drought, preventing a farmer from having to reduce the size of their herd prematurely or secure water from a more expensive source. | **2018 Missouri Drought Response Report** https://dnr.mo.gov/document-search/2018-missouri-drought-numbers-pub2747 | 1-Reducing Impacts | Improve resilience<br><br>Reduce Impact/Damage | Northwest<br>North Central<br>Northeast<br>West Central<br>East Central<br>Southwest<br>South Central<br>Southeast | Missouri Department of Conservation<br><br>Missouri Department of Natural Resources |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Alternate Sources | | | | | | |
| Applicable Drought Phase | Phase 3 – Conservation | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Use an existing, emergency water system interconnection to a neighboring water system. (3) | Municipal | Interconnections to neighboring water systems that were built primarily for emergency purposes in the event of a failure of treatment or pumping systems can also be used during drought to extend existing supplies. | Section 3 of the Missouri Drought Mitigation and Response Plan | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce Impact/Damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central<br>Central<br>East Central<br>Southeast | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Alternate Sources | | | | | | |
| Applicable Drought Phase | Phase 4 – Drought Emergency | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Use of certified potable water hauling water trucks to deliver water to communities with a diminished, insufficient supply and immediate need. Temporary drinking water distributions centers provide access where customers can fill containers for essential home uses. (4) | Municipal | Tanker trucks certified for hauling potable water can be used in extreme cases to protect public health when existing supplies are depleted. This strategy has limited applicability, given the small volume of water that can be hauled, relative to a community's demand. | **Guidelines for Hauling Bulk Drinking Water For Emergency Distribution**<br>https://health.mo.gov/emergencies/ert/pdf/BulkDrinkingWater.pdf | 1-Reducing Impacts | Reduce Impact/Damages | Northwest<br>North Central<br>Northeast<br>West Central | Missouri Department of Public Safety<br><br>Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Category** | Supply | | | | | | |
| **Subcategory** | Assistance | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Provide technical, planning, and financial assistance to identify alternative water supplies that increase resilience to drought. (9) | All | State agencies can be instrumental in providing much-needed technical assistance, especially for small communities, to identify alternative water supplies prior to and during a drought. | **Missouri Department of Natural Resources – Financial Assistance Center. Drinking water funding opportunities**: https://dnr.mo.gov/water/business-industry-other-entities/financial-opportunities/financial-assistance-center/drinking-water | 3-Enhancing Resiliency | Improve Resiliency<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources |
| Promote, fund, and provide technical assistance for stream restoration projects that stabilize streambanks and reduce erosion. (10) | Environment | Sediment from eroding streams can deposit in downstream water supply reservoirs, lowering their capacity and reducing their ability to serve as a reliable water supply during extended droughts. | **Example Stream Restoration Project at Castlewood State Park** https://www.nature.org/en-us/about-us/where-we-work/united-states/missouri/stories-in-missouri/castlewood-restoration/ | 1-Reducing Impacts | Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>Missouri Department of Conservation |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Assistance | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Provide technical assistance to evaluate a reservoir's capacity to meet current and projected water supply needs during drought. (11) | Municipal | MoDNR performs water supply studies and hydrologic and water resource engineering assistance to communities on how to allocate their water supplies to meet demands during an extended multi-year drought. Studies include bathymetric surveys to more accurately estimate reservoir capacities and modeling to estimate firm yield. | **The 2013 Missouri Water Supply Study includes information about numerous, existing reservoirs and strategies they use to maintain ample supplies in reservoirs.** https://dnr.mo.gov/document-search/missouri-water-supply-study-2013 | 3-Enhancing Resiliency | Improve Resiliency<br><br>Reduce susceptibility<br><br>Reduce impact/damages | Northwest<br>North Central<br>Northeast<br>West Central | Missouri Department of Natural Resources, Geological Survey, Water Resources Center<br><br>U.S. Geological Survey<br><br>Local Groups and Entites (Ctities, Counties, Utilities) |
| Fund water system improvements for drought mitigation and resiliency. (12) | Municipal | This state-level action recognizes, prioritizes, and supports projects that improve drought resiliency through already-in-place funding programs such as the State Revolving Fund or new funding mechanisms and programs. | **MoDNR Financial Assistance Center** https://dnr.mo.gov/water/business-industry-other-entities/financial-opportunities/financial-assistance-center | 3-Enhancing Resiliency | Improve Resiliency<br>Reduce susceptibility<br>Reduce impact/damages | All | Missouri Department of Natural Resources |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Increase Storage | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| Explore technologies for water supply banking, floodwater diversion storage, and managed aquifer recharge. (13) | All | An increase in the severity and frequency of extreme events is an expected outcome of our changing climate. Communities are increasingly evaluating strategies that enhance resiliency to both flooding and drought. Strategies such as diversion and storage of floodwater and managed aquifer recharge both reduce impacts to flooding and provide storage that can be used as a source of supply during drought. | **The National Groundwater Association prepared a fact sheet on Managed Aquifer Recharge as a water supply tool:** https://www.ngwa.org/docs/default-source/default-document-library/publications/information-briefs/managed-aquifer-recharge-a-water-supply-management-tool.pdf | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce Impact/damages<br><br>Reduce susceptibility | All | Regulatory Agencies |
| Reduce sedimentation and loss of storage capacity in farm ponds and reservoirs used for water supply through creation of wetlands, reforestation, cover cropping, and other means of minimizing erosion. (15) | All | Sedimentation of ponds and reservoirs reduces storage capacity and makes supplies less resilient to drought. The creation of wetlands, re-forestation, cover cropping, and various other methods can be employed to limit soil erosion and reduce the rate of sedimentation in water supply ponds and reservoirs. | **Missouri Soil and Water Conservation Program** https://dnr.mo.gov/land-geology/soil-water-conservation | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>Missouri Department of Conservation<br><br>Missouri Department of Agriculture |
| Enhance storage at existing water supply reservoirs. (17) | Municipal | Enhancing reservoir storage helps maintain water supplies during drought, when inflows are reduced. Examples of strategies that enhance reservoir storage include deepening or dredging to remove accumulated sediment; raising the level of | **The 2013 Missouri Water Supply Study includes information about numerous, existing reservoirs and strategies they use to maintain ample supplies in reservoirs.** | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce Impact/damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central | Missouri Department of Natural Resources<br><br>Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Supply |
|---|---|
| Subcategory | Increase Storage |
| Applicable Drought Phase | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| | | the dam; raising the level of the outlet control structure; and making repairs to a leaky dam. Raising the level of the dam is only viable if the watershed can handle a larger reservoir. | https://dnr.mo.gov/document-search/missouri-water-supply-study-2013 | | | | Regional Water Commissions |
| Implement aquifer storage and recovery (ASR). (18) | Municipal | ASR is the use of aquifers as a water storage bank. Deposits are made in times of surface water supply surplus and withdrawals occur when available surface water supply falls short of demand. ASR requires careful planning and evaluation to confirm that the treated surface water is compatible with the bedrock formations and no reactions occur that compromise the quality of both the native and stored water. By storing surface water in the ground, there is no additional evaporative water loss compared to surface water storage; however, it is also important to consider that all the surface water stored in the aquifer may not be recoverable. | **FEMA Fact Sheet on Climate Resilient Mitigation Activities - Aquifer Storage and Recovery** https://www.epa.gov/sites/default/files/2016-04/documents/fema_aquifer_storage_recovery_fact_sheet-sept_2015.pdf | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce Impact/damages<br>Reduce susceptibility | Central<br>East Central<br>Southwest<br>South Central | Regulatory Agencies<br><br>Local Groups and Entities (Cities, Counties, Utilities) |
| Removal of sediment from farm ponds to increase available storage capacity used to | Agriculture | Erosion and sedimentation in ponds reduce storage capacity which can result in farmers and livestock | **Soil and Water Conservation Cost-Share Practices** | 3-Enhancing Resiliency | Improve Resilience<br><br>Reduce Impact/Damages | All | Local Groups and Entities (Citites, Counties, Utilities) |

| | |
|---|---|
| **Category** | Supply |
| **Subcategory** | Increase Storage |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| supply water for crops and/or livestock. (112) | | producers running out of water quicker in drought events. This can reduce the financial impacts of drought or at least give more time for the impacted farmers/livestock producers to secure alternate water supply. | https://dnr.mo.gov/land-geology/businesses-landowners-permittees/financial-technical-assistance/soil-water-conservation-cost-share-practices<br><br>**2018 Missouri Drought Response Report**<br>https://dnr.mo.gov/document-search/2018-missouri-drought-numbers-pub2747 | | | | |
| Install storage tanks to supplement storage capacity of wells and/or ponds. (117) | Agriculture | Storage tanks can supplement ponds and wells used by farmers and livestock producers during drought events. Water can be stored in times of excess precipitation or in preparation of potential future drought and used to supplement low flow volumes from wells or extend the amount of time before a pond runs dry. | | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce Impact/damages | All | Missouri Department of Natural Resources<br><br>Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Increase Storage | | | | | | |
| Applicable Drought Phase | Phase 3 – Conservation | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Request temporary authorization from regulatory agencies to reduce water releases from reservoirs, in accordance with an agreed upon schedule of reductions within a formal drought contingency plan. (14) | All | Unplanned or emergency deviations from the Water Control Plan of a reservoir owned and operated by the USACE are allowed under certain conditions. Provided storage is available, in some instances, drought emergency declaration may allow the purchase of emergency-use storage to water livestock. | **USACE, 2016. Water Control Management (ER 1110-2-240), Chapter 3.** https://www.publications.usace.army.mil/portals/76/publications/engineerregulations/er_1110-2-240.pdf | 3-Enhancing Resiliency | Improve resilience<br>Reduce Impact/damages<br>Reduce susceptibility | All | Regulatory Agencies<br><br>Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Increase Supply | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Improve the reliability of water supplies for livestock and pasture production during periods of drought. (19) | Agriculture | Local, state, and federal agencies should continue to work together with livestock producers to invest in restoring existing surface water impoundments, creating new impoundments, and/or developing additional infrastructure such as emergency connections to public water supplies or new groundwater wells as a proactive approach to alleviating future shortages | **Section 7.3 of the 2020 Missouri Water Resources Plan outlines needs of water supplies for livestock and pasture production:** https://dnr.mo.gov/water/what-were-doing/water-planning/missouri-water-resources-plan | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages | All | U.S. Department of Agriculture, Rural Development Program<br><br>Missouri Department of Agriculture<br><br>U.S. Department of Agriculture, Natural Resource |

| | |
|---|---|
| **Category** | Supply |
| **Subcategory** | Increase Supply |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| | | during drought. New cost-sharing opportunities including grant programs need to be created to help build resiliency to livestock water supplies. This is of critical importance in northern Missouri where drought often threatens livestock water supplies and hay production. | | | | | Conservation Service |
| Construct floating or multi-level intake structures in rivers or reservoirs. (21) | All | Floating or multi-level intake structures can help maintain access to water during drought conditions, when lake or river levels may drop at or below fixed intakes. | | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Increase Supply | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Develop reclaimed (recycled) water systems for non-potable uses, such as landscape irrigation, non-food crop irrigation, cooling towers and vehicle washing. (23) | All | Wastewater that would normally be discharged to a receiving body after treatment can be recycled and used for agricultural, industrial, and commercial non-potable uses. Reclaimed water reduces the demand that would otherwise be placed on drinking water, and helps build a drought-resilient, sustainable supply. | **The WaterReuse organization publishes a Manual of Practice titled How to Develop a Water Reuse Program.** https://watereuse.org/educate/fact-sheets/<br><br>**The USEPA's Guidelines for Water Reuse (2012)** https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf<br><br>**EPA Water Reuse website**: https://www.epa.gov/waterreuse | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions<br><br>Regulatory Agencies |
| Change state regulations to allow the discharge of treated wastewater to water supply streams or reservoirs to supplement sources of supply (indirect potable reuse). (25) | Municipal | Indirect potable reuse uses an environmental buffer, such as a lake or river before the water is treated at a drinking water treatment plant. Although regulations currently prohibit the deliberate augmentation of a drinking water source with treated, reclaimed water (indirect potable reuse) in Missouri, rule changes could allow for wastewater flows to be used to supplement sources of supply, especially those that may be limited during drought. | **The WaterReuse organization publishes a Manual of Practice titled How to Develop a Water Reuse Program.** https://watereuse.org/educate/fact-sheets/<br><br>**The USEPA's Guidelines for Water Reuse (2012)** https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf<br><br>**EPA Water Reuse website**: https://www.epa.gov/waterreuse | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions<br><br>Regulatory Agencies |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Increase Supply | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Restore water bodies that have impaired designated uses for use as a water supply. (27) | Municipal | If impaired water bodies with limited designated uses can be restored, they can potentially serve as primary or secondary water supply sources. Assessment, inspections, permitting, enforcement, technical assistance and funding are all critical elements to improving the quality of impaired waters and increasing their potential uses. | | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce susceptibility | All | Regulatory AgenciesLocal Groups and Entities (Cities, Counties, Utilities) |
| Reallocate water supply storage in federal reservoirs where additional storage could be allocated for municipal and industrial supply. (26) | Municipal | Water suppliers may request that USACE study and approve reallocation of water supply storage in federally owned reservoirs to meet the needs of public water suppliers. The Water Supply Act of 1958 enables USACE to approve reallocation of storage at federal reservoirs for municipal and industrial water supply if the modification does not seriously affect authorized project purposes. The cost, length of time, and difficulty in receiving an approval for reallocation should be considered when selecting alternate supply options. | **USACE, 2016. Water Control Management (ER 1110-2-240), Chapter 3**. https://www.publications.usace.army.mil/portals/76/publications/engineerregulations/er_1110-2-240.pdf<br><br>**Tri-State Water Resource Coalition Reallocation Analysis.** http://tristatewater.org/?page_id=12 | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | U.S. Army, Corps of Engineers<br><br>Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissons |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Increase Supply | | | | | | |
| Applicable Drought Phase | Phase 3 – Conservation | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholder** |
| Drill new wells and deepen existing wells. (20) | All | Drilling wells to provide an alternate source of supply is a common strategy, where groundwater is of sufficient volume and quality to support intended uses. Likewise, deepening existing wells can increase yield or provide access to a deeper, more sustainable source of supply during drought. | **MoDNR Wells and Drilling website** https://dnr.mo.gov/water/business-industry-other-entities/permits-certification-engineering-fees/wells-drilling<br><br>**MoDNR Well Information Management System (WIMS 2.0) – Permit Application Portal** https://dnr.mo.gov/water/business-industry-other-entities/reporting/well-information-management-system-wims | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | Central<br>East Central<br>Southwest<br>South Central<br>Southeast | Missouri Department of Natural Resources |
| Lower groundwater well pumps. (22) | All | Lowering well pumps may be an effective strategy to improve yield or maintain supply during extended drought, which has resulted in lower water levels in the aquifer. Shallow, domestic and agricultural wells are especially vulnerable, as they the shallow aquifers that they tap are more susceptible to impacts from drought. | **The Texas Ag&M AgriLife Extension guide to protecting your well during a drought**: https://twon.tamu.edu/wp-content/uploads/sites/3/2021/06/protect-your-water-well-during-drought.pdf | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | Central<br>East Central<br>Southwest<br>South Central<br>Southeast | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Increase Supply | | | | | | |
| Applicable Drought Phase | Phase 3 – Conservation | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholder** |
| Augment reservoir inflows by pumping from nearby streams outside of the reservoir's drainage area, especially during high stream flows, to keep water levels in reservoirs near full. (24) | Municipal | Some Missouri lakes and reservoirs are too small in size and drainage area to satisfy local needs during drought. Other sources, including pumping from nearby streams are used to increase the inflow to the reservoirs. Pumping from nearby streams into the reservoirs during high stream flows, to keep water levels in lakes near full, can help mitigate against loss of supply during drought. | **The 2013 Missouri Water Supply Study includes information about numerous, existing reservoirs and strategies they use to maintain ample supplies in reservoirs.** https://dnr.mo.gov/document-search/missouri-water-supply-study-2013 | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central | Regulatory Agencies<br><br>Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Consider public/private partnerships to augment or replace local, limited water supplies. (28) | All | Privatizing a water system is sometimes considered when a municipally-owned system struggles technically, financially, and/or administratively to provide safe and reliable service. Private companies can leverage capital reserves, technical expertise, and economies of scale to deliver quality, cost-effective service to customers. Privatization may also be an option to enhance the source of supply. For example, a community with a limited source of supply may benefit from a partnership with a nearby, privately owned utility that has a larger, more resilient source of supply. | | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |
| Develop instream flow protections. (30) | Environment | Many states have already, or are in the process of developing instream flow standards to protect fish and aquatic resources. The standards are used to set minimum releases from upstream control structures like dams or limit the amount of withdrawals that can occur. While these standards may limit the availability of water for human needs, they help balance competing uses especially during times of water | | 1-Reducing Impacts | Reduce impact/damages | All | Regulatory Agencies |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | scarcity. Interagency instream flow working groups may result in more effective response to stream flow alterations and help to establish a framework for determining appropriate instream flows. | | | | | |
| Encourage or require communities to include drought mitigation and response elements in their local emergency operations plans. (31) | Municipal | Many existing Emergency Operations Plans do not address drought response. Effective plans are developed before drought occurs and help identify trigger points and responses to extend critical water supplies; identify alternative water sources; establish interconnections; develop education programs and demand reduction strategies; define implementation and enforcement mechanisms; and address water conservation during drought conditions. | **Drought Ready Communities** https://drought.unl.edu/archive/Documents/NDMC/Planning/DRC_Guide.pdf<br><br>**Drought and Infrastructure: A Planning Guide** https://www.cisa.gov/sites/default/files/publications/Drought_and_Infrastructure_A_Planning_Guide_508c.pdf | 7-Planning the Response | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>Regional Water Commissions<br><br>Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Promote, support and fund water supply regionalization. (32) | Municipal | Typically, regionalization decreases the operation and maintenance portion of user rates. Larger water systems have greater technical, managerial, and financial capabilities in general. This leads to quicker response during emergencies, such as drought, and a better position to finance capital improvement projects that may improve resilience to drought. Missouri's State Revolving Fund loan program awards additional priority points for regionalization projects. | **The 2020 Missouri Water Resources Plan outlines the benefits of regionalization.** https://dnr.mo.gov/water/what-were-doing/water-planning/missouri-water-resources-plan<br><br>**MoDNR Clean Water Regionalization Information:** https://dnr.mo.gov/water/what-were-doing/water-planning/missouri-water-resources-plan | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Regulatory Agencies<br><br>Local Groups and Entities (Citites, Counties, Utilities) |
| Conduct a drought and water shortage tabletop exercise and provide drought workshops and training for other state and local water users and managers. (33) | Municipal | The purpose of a tabletop exercise is to review plans and procedures that govern state-, basin-, and/or local-level responses to drought and water shortages. Tabletop exercises foster communication between local, state, federal and other entities that are critical to drought response. They also clarify roles and responsibilities. Workshops and drought training can also be useful to expand the water manager's technical expertise that is necessary for proper drought planning and response. | **South Carolina Example:** http://www.scdrought.com/pdf/2019_SC-DroughtTTX_ReportSummary.pdf | 8-Clarifying Roles & Responsibilities | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>University of Missouri, State Climatologist<br><br>Environmental Protection Agency<br><br>Local Groups and Entities (Citites, Counties, Utilities) |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Conduct a statewide survey of water utility interconnections. (34) | Municipal | Through statewide assessment of water system interconnections, MoDNR can better provide technical assistance and targeted funding to enhance existing interconnections and build new ones, increasing resilience to drought. A statewide study of interconnections can assess the existing size and capabilities of interconnections; determine where there may be bottlenecks or limitations due to inadequate pumps, pipes, other equipment; and identify where new interconnections may useful. | | 7-Planning the Response | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources |

| Category | Supply | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Policy | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| Adopt development standards which preserve and enhance groundwater recharge and promote nature-based solutions to build resilience. (35) | All | In areas where shallow groundwater is a source of supply (e.g., glacial sands of northwest Missouri), enhancing local recharge can increase the volume of groundwater in an aquifer, and sustain the source longer during drought periods. | **FEMA's Manual on Building Community Resilience with Nature-Based Solutions**: https://www.fema.gov/sites/default/files/documents/fema_riskmap-nature-based-solutions-guide_2021.pdf | 3-Enhancing Resiliency | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Southeast | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

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|---|---|---|---|---|---|---|---|
| **Category** | Supply | | | | | | |
| **Subcategory** | Water Efficiency | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Promote rainwater harvesting methods such as cisterns or rain barrels and cooling condensate capture for non-potable uses such as landscape irrigation. (36) | All | Rainwater harvesting methods can help reduce demand on potable supplies and have the benefit of extending potable supplies during drought. This strategy is taken at the customer-level, but can be promoted and incentivized through rebates, workshops, training and outreach by the public water supplier. | **Information on residential use of rain barrels and cisterns** https://bawsca.org/uploads/userfiles/files/Rain%20Barrels/BASMAARainBarrelGuidance.pdf<br><br>**FEMA's manual on Building Community Resilience with Nature-Based Solutions** https://www.fema.gov/sites/default/files/documents/fema_riskmap-nature-based-solutions-guide_2021.pdf | 4-Promoting Water Conservation | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regional Water Commissions |
| Explore beneficial uses for flushed water, such as irrigation, construction, fire-fighting storage or other non-drinking water uses. (37) | Municipal | Saving water that is routinely flushed from drinking water systems for irrigation, fire fighting or other non-potable uses helps reduce the demand on supplies that could be limited during drought. | **EPA Reuse and Recycling** https://www.epa.gov/waterreuse<br><br>**EPA Guidelines for Water Reuse** https://www.epa.gov/waterreuse/guidelines-water-reuse | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |
| Recirculate backwash water to the head of water treatment plant and identify other means to reduce process water loss. (38) | Municipal | Reusing process water at water treatment plants, instead of discharging will reduce water losses and extend available supply. | | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

| **Category** | Education - Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| **Subcategory** | Assistance | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| The Department of Agriculture and state universities, should conduct workshops on crop survival and livestock management during drought. (89) | Agriculture | Agricultural producers are usually the first to feel the effects of drought and the most damage from drought occurs in the agricultural sector. Information can be provided to producers in areas affected by drought on monitoring drought conditions, monitoring livestock and the risk of forage poisoning during drought, efficient irrigation techniques, manage price risk and volatility through futures markets, LRP insurance, forward contracts, and where to get assistance. | **University of Missouri Extension Drought Resources** https://extension.missouri.edu/programs/drought-resources | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Agriculture<br><br>University of Missouri, Cooperative Extension Service |
| The University of Missouri Extension and other state universities should conduct routine outreach with the agriculture sector to build awareness of the drought planning and response information and guides available to them through the University of Missouri Extension and other sources. (90) | Agriculture | The University of Missouri Extension has numerous on-line resources to support farmers with drought planning and during a drought. | **University of Missouri Extension Agricultural Electronic Bulletin Board - Drought Information** http://agebb.missouri.edu/drought/agriculture/agriculture.php | 1-Reducing Impacts | Reduce impact/damages | All | University of Missouri, Cooperative Extension Service |

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|---|---|---|---|---|---|---|---|
| **Category** | Education - Outreach | | | | | | |
| **Subcategory** | Assistance | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Improve outreach and education on the hay marketplace. (91) | Agriculture | Missouri is a major hay producer. Hay prices fluctuate during drought conditions. The Internet Hay Exchange is an online marketplace for buying and selling hay. The Hay Exchange connects buyers and sellers by state and area code. Producers in non-drought regions can connect with buyers in drought affected regions and vise versa.<br><br>Also, the USDA Farm Service Agency (FSA) maintains listings of counties eligible for emergency haying or grazing on CRP land affected by server drought. | **Internet Hay Exchange**<br>http://www.hayexchange.com/mo.php<br><br>**Emergency Haying and Grazing**<br>https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/emergency-haying-and-grazing/index | 7-Planning the Response | Improve resilience<br><br>Reduce impact/damages | Northeast<br>West Central<br>Central<br>Southwest<br>South Central | Missouri Department of Agriculture<br><br>U. S. Department of Agriculture, Farm Service Agency |

| Category | Education - Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Educate agricultural producers on production modifications and technical assistance available to lessen drought impacts. (93) | Agriculture | Agricultural producers are usually the first to feel the effects of drought and the most damage from drought occurs in the agricultural sector. Information should be made available to producers on monitoring drought conditions, monitoring livestock and the risk of forage poisoning during drought, efficient irrigation techniques, where to get assistance, and other actions to lessen the impact of drought on the agricultural sector. | **University of Missouri Extension Drought Resources** https://extension.missouri.edu/programs/drought-resources | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | Northeast<br>West Central<br>Central<br>Southwest | Missouri Department of Agriculture<br><br>University of Missouri, Cooperative Extension Service |
| Establish statewide water conservation guidelines for drought conditions. (95) | All | Effective plans are developed before drought occurs and help identify trigger points and responses to extend critical water supplies; identify alternative water sources; establish interconnections; develop education programs and demand reduction strategies; define implementation and enforcement mechanisms; and address water | **EPA - Drought Resilience and Water Conservation** https://www.epa.gov/water-research/drought-resilience-and-water-conservation | 4-Promoting Water Conservation | Improve resilience<br><br>Reduce impact/damages | All | Missouri Department of Natural Resources<br><br>Missouri Department of Agriculture<br><br>Local Groups and Entities (Cities, Counties, Utilitites)<br><br>Regulatory Agencies |

| Category | Education - Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | conservation during drought conditions. Establishing statewide guidelines is especially helpful to utilities and water users that need technical and planning support. | | | | | |
| Encourage local level drought planning and increase community/local level drought planning assistance and identify leaders at local level (i.e., create Drought Ready Communities). (98) | Municipal | Local communities and agencies should have a drought plan in place prior to a drought event. Promotes drought planning on a local level which can help further mitigate impacts of drought, increase resiliency, and alleviate the burden on state agencies during drought events. | **Drought Ready Communities** https://drought.unl.edu/archive/Documents/NDMC/Planning/DRC_Guide.pdf<br><br>**Drought and Infrastructure: A Planning Guide** https://www.cisa.gov/sites/default/files/publications/Drought_and_Infrastructure_A_Planning_Guide_508c.pdf | 7-Planning the Response | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Loccal Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

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|---|---|
| **Category** | Education - Outreach |
| **Subcategory** | Planning |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Encourage livestock producers to diversify forage production with native warm season grasses and forbs. (120) | Agriculture | Native warm season grasses are deep-rooted which makes them less susceptible to drought than cool season grasses which currently dominate Missouri's pastures and hayfields. Incentives are available from the USDA NRCS and Missouri Department of Conservation to encourage landowners to convert to warm season native grasses. | **USDA NRCS (MO) Native Forage Initiative** https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives/missouri/environmental-quality<br><br>**Missouri Department of Conservation** https://mdc.mo.gov/your-property/improve-your-property/eqip-native-forage-initiative | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | U.S. Department of Agriculture, Natural Resource Conservation Service, Native Forage Initiative<br><br>Missouri Department of Conservation |

| Category | Education - Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Phase 1 – Incipient Drought | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Support and advertise reporting tools, such as the Drought Impact Reporter (DIR) and the Condition Monitoring Observer Reports (CMOR). (96) | All | The DIR is an interactive database of drought impacts across the U.S. from Stakeholders, government, media, and other reports. The CMOR is a reporting tool that allows citizens to submit observation reports and pictures relating to drought, which are then presented in a map that can be used to view and access submitted information and attachments. Both reporting tools can help inform decisionmakers on proper mitigation actions to take given the severity of local drought conditions, as well as providing a record of historical drought conditions for use in additional analyses. | **Drought Impact Reporter:** https://droughtreporter.unl.edu/map/<br><br>**Condition Monitoring Observer Reports:** https://droughtimpacts.unl.edu/Tools/ConditionMonitoringObservations.aspx | 2-Increasing Public Awareness | Improve resilience | All | Missouri Department of Natural Resources<br><br>University of Missouri, State Climatologist |
| Encourage local agencies to use newsletters, website updates and social media to provide accurate information and updates about the drought and potential actions to the public. (97) | Municipal | Social media is a fast way to reach many people with up-to-date information when conditions are changing. Information can be provided on current conditions, what to do, and where to get more information. | **National Weather Service** https://www.weather.gov/wrn/summer2020-drought-sm<br><br>**National Drought Mitigation Center** https://drought.unl.edu/Publications/SocialMediaResources.aspx | 2-Increasing Public Awareness | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Education - Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Phase 1 – Incipient Drought | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Coordinate drought-related communication (e.g., low water levels, campfire restrictions, etc.) for in-state and out-of-state tourists, including social media, email databases and tourism industry partners. (99) | Tourism | Moderate to severe drought conditions can result in boating accidents due to low lake levels, poor conditions for float trips, and wildfires from campfires. Providing information of drought-related restrictions on tourist activities can forewarn tourists on local conditions. This action can also potentially mitigate economic losses on tourism from drought. | **Missouri State Parks**<br>https://mostateparks.com<br><br>**Missouri Division of Tourism**<br>https://www.visitmo.com/travel-resources/ | 2-Increasing Public Awareness | Improve resilience<br><br>Reduce impact/damages | West Central<br>Central<br>East Central<br>Southwest | Missouri Division of Tourism<br><br>Missouri Department of Natural Resources, Missouri State Parks |

| Category | Education - Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Policy | | | | | | |
| Applicable Drought Phase | Phase 1 – Incipient Drought | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| Enact burn bans during drought. (101) | Municipal | Prohibiting burning of yard waste or other organic material will help prevent wildfires during drought by eliminating common sources of ignition. | | 1-Reducing impacts | Reduce impact/damages | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Education – Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| Offer water efficiency/water conservation workshops covering water-saving tips for your customers. (102) | Municipal | Homeowners and business owners need information to know what to do to be water efficient. Technology is available to improve indoor and outdoor water use efficiency if homeowners and business owners are aware of its availability and benefits. Routine water conservation workshops can help customers maintain a water conservation mindset and workshops during an early phase of | **H2ouse.org - Conservation** https://www.h2ouse.org/water-conservation/<br><br>**EPA WaterSense** https://www.epa.gov/watersense<br><br>**City of Columbia (MO) - Conservation** https://www.como.gov/utilities/columbia-power-partners/water-conservation/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Education – Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| | | drought can help extend a dwindling supply. | **My Drop Counts.org - Conservation** [https://mydropcounts.org/conserve-our-water/](https://mydropcounts.org/conserve-our-water/) | | | | |
| Encourage local agencies to collaborate with neighboring utilities to implement the same water use restrictions and announce the end of drought emergency and water restrictions. (105) | Municipal | Neighboring water providers may share newspaper, radio and TV market areas, thus providers with different water use restrictions may be confusing to customers and therefore ignored. Water providers in shared media markets should coordinate messaging, water restrictions, and ordinances to the extent possible. | | 8-Clarifying Roles & Responsibilities | Improve resilience | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Encourage local water managers to partner with private sector and volunteer organizations that share common interests or special expertise, such as water-efficient landscaping. (106) | Municipal | Local businesses such as landscape nurseries and volunteer organizations such as the Sierra Club or Master Gardeners can be engaged with water providers to conduct landscape workshops or create demonstration gardens to promote water-efficient landscaping. | | 4-Promoting Water Conservation | Improve resilience | All | Local Groups and Entities (Cities, Counties, Utilities) |

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|---|---|
| **Category** | Education – Outreach |
| **Subcategory** | Water Efficiency |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Collaborate with major water users supplied by a municipal source to identify water-saving measures they can take without harming their business. Provide commercial, industrial, and institutional water audits with recommendations for cost-effective water efficiency improvements. (107) | Municipal | Commercial, industrial, and institutional water audits for large water-users can identify opportunities to save water and cut costs. Water savings can be promoted by the company as good public relations and help promote water use efficiency in the community. | **EPA WaterSense at Work** https://www.epa.gov/sites/default/files/2017-02/documents/watersense-at-work_final_508c3.pdf<br><br>**Consortium of Energy Efficiency standards include water efficiency standards for commercial dishwashers, ice machines and commercial clothes washers. Credits can be provided for appliances that meet these standards:** https://cee1.org/content/cee-program-resources<br><br>**Be Water Wise.com** https://socalwatersmart.com/en/commercial/rebates/available-rebates/commercial-devices/<br><br>**San Antonio Water System rebate programs** https://www.saws.org/conservation/commercial-programs-rebates/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

| Category | Education - Outreach | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Phase 1 – Incipient Drought | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| 'Engage major employers, local businesses and county officials to help spread drought related messages and act as water conservation "models" within the community. (101) | Municipal | Sets an example for members of the community to follow and builds community spirit when addressing drought events. It also encourages businesses to be water efficient. | **EPA Using Water Efficiently: Ideas for Communities** https://www.epa.gov/sites/default/files/2017-03/documents/ws-ideas-for-communities.pdf | 4-Promoting Water Conservation | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Provide drought messaging through school programs and public service announcements during response phases of drought. (103) | Municipal | School programs are an effective way to inform children, who inform parents, about ways to use less water during drought conditions, and the importance of water for the community. | **Resources for Teachers and Students** https://www.drought.gov/what-is-drought/resources-for-teachers-and-students | 4-Promoting Water Conservation | Improve resilience<br><br>Reduce impact/damages | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Develop and implement a variety of outreach methods to spread the word on the benefits of water conservation and water use efficiency. (104) | Municipal | Water conservation tips and strategies to use water more efficiently can be distributed to utility customers through the web, social media, bill inserts, television, radio, and various other means. Effective outreach strategies should be identified and used both prior to and during drought. | **US EPA WaterSense** https://www.epa.gov/watersense<br><br>**The Alliance for Water Efficiency** https://www.allianceforwaterefficiency.org/ | 4-Promoting Water Conservation | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

| Category | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Monitoring | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Partner with the USGS to strategically increase the number of stream gages across the state in regions with data gaps and where surface water is the primary source of supply. Increase the availability of stream gage data and make information available as close to real-time conditions as possible. (67) | All | Expanding Missouri's stream gage network will help monitor surface water availability for state agencies, farmers, planners, and other water users. More accurate and detailed stream gage data increases the accuracy of reservoir system modeling and allows for better planning. | **USGS - What is a stream gage?** https://www.usgs.gov/centers/utah-water-science-center/science/what-streamgage?qt-science_center_objects=0<br><br>**USGS Current Water Data for Missouri** https://waterdata.usgs.gov/mo/nwis/rt<br><br>**USGS National Water Information System: Mapper** https://maps.waterdata.usgs.gov/mapper/index.html | 6-Improving Monitoring | Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>United States Geological Survey |
| Update and refine aquifer mapping to better quantify volume and location of water resources. (68) | All | Updated mapping allows for better quantification of water volume in aquifers and location of water resources of sufficient quality for municipal and/or agricultural use. This helps state agencies and water users understand the availability of groundwater, impacts of drought on aquifer drawdown, and potentially maximize the utilization of groundwater where applicable. | **Missouri Aquifer Information** https://dnr.mo.gov/water/hows-water/state-water/groundwater/aquifer-information-groundwater-availability | 6-Improving Monitoring | Reduce susceptibility | Central<br>East Central<br>Southwest<br>South Central<br>Southeast | Missouri Department of Natural Resources |
| Increase weather and climate monitoring (Mesonet) and expand manual/automated data | All | Drought monitoring infrastructure, including Missouri's Mesonet, provides the information necessary to monitor and anticipate drought | **Missouri Mesonet (Weather Station Network)** | 6-Improving Monitoring | Improve resilience | All | University of Missouri, State Climatologist |

| Category | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Monitoring | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| network on precipitation, hydrology, soil moisture/infiltration to support drought assessment. (70) | | events. Providing accurate information to impacted residents, local governments, and state agencies is essential to effectively prepare for and respond to drought, and support drought research, assessment and prediction. | http://agebb.missouri.edu/weather/stations/ http://agebb.missouri.edu/weather/realTime/maps/index.php | | Reduce susceptibility | | Missouri Department of Natural Resources |
| Develop methodology for state agencies to use regarding proper data collection of various impacts from drought. Provide guidance to state agencies on data collection in order to track drought impacts. (72) | All | Will allow for quantification of drought impacts on various sectors of Missouri's economy and residents in a more consistent manner that allows for easier analysis in the future. | Section 4 of the Missouri Drought Mitigation and Response Plan provides a summary of methods that were used to assess economic impacts from drought. | 6-Improving Monitoring | Reduce impact/damages | All | Missouri Department of Natural Resources |
| Convene the Climate and Weather Committee (CWC) and the Drought Assessment Committee (DAC) at least every other year to identify and discuss potential improvements to data collection and monitoring and the use of evolving monitoring and forecasting tools that may improve drought forecasting, planning, response, and research in Missouri. (73) | All | Data collection and monitoring is the backbone of effective drought planning. Routine review and assessment of data gaps and new monitoring and forecasting methods and tools is essential to improve drought forecasting, enhance drought planning, and support drought research. | | 8-Clarifying Roles & Responsibilities | Improve resilience<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources, Geological Survey, Water Resources Center |
| When and where available, use products such as the National Weather Service's Ensemble Streamflow | All | Having estimate of seasonal, low stream flows will allow state agencies water managers more time to prepare for potential | **The National Weather Service's website has information on the ESP, HEFS and other** | 6-Improving Monitoring | Reduce susceptibility | All | Missouri Department of Natural Resources |

| Category | Education - Data | | | | | | |
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| Subcategory | Monitoring | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Prediction (ESP) and Hydrologic Ensemble Forecasting Service (HEFS) for both short-term (days) and long-range (months) streamflow forecasts, as a planning tool for water managers. (74) | | reductions in water supply availability and mitigate the resulting impacts. Ensemble streamflow forecasting tools are currently available for parts of the U.S., but their availability and application are still limited, especially in the Missouri River Basin; however, as these tools are further developed for the central U.S., including Missouri, they can help water managers better prepare for drought well in advance of them occurring. | **streamflow prediction tools.** www.weather.gov | | | | U.S. Department of Agriculture, Natural Resource Conservation Service |
| Use crop reporting districts instead of climate divisions for climate analysis, drought monitoring, and response. (75) | All | There are nine crop reporting districts in Missouri which offers more detailed spatial resolution than the six climate divisions. Crop reporting districts also better represent the variation in climate across the state than climate divisions. | **Map of Missouri crop reporting districts and counties:** https://www.nass.usda.gov/Charts_and_Maps/Crops_County/boundary_maps/mo.pdf | 6-Improving Monitoring | Improve resilience | All | Missouri Department of Natural Resources<br><br>National Oceanic and Atmospheric Administration (NOAA)<br><br>University of Missouri, State Climatologist |

| Category | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Monitoring | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Monitor the Drought Early Warning System (DEWS) for the two regions that overlap with Missouri (Missouri River Basin and Midwest DEWS) to stay aware of changing conditions in an effort to help predict drought and begin mitigation actions accordingly. (76) | All | Drought early warning systems (DEWS) use networks of federal, tribal, state, local, and academic partners to make climate and drought science accessible and useful for decision makers. These systems improve stakeholders' capacity to monitor, forecast, plan for, and cope with the impacts of drought.<br><br>The Midwest DEWS covers the entire state of Missouri. The Missouri River Basin DEWS covers most of western Missouri and an area along the Missouri River until it reaches the Mississippi River north of St. Louis.<br><br>Drought impacts vary from region to region. The development and implementation of regional DEWS allows for responsiveness to particular geographic and hydrologic circumstances. | **Missouri River Basin DEWS** https://www.drought.gov/dews/missouri-river-basin<br><br>**Midwest DEWS** https://www.drought.gov/dews/midwest | 6-Improving Monitoring | Improve resilience<br><br>Reduce impact/damages | All | Missouri Department of Natural Resources<br><br>Missouri Department of Agriculture |
| Monitor websites such as Drought.gov and the U.S. Drought Monitor to stay aware of changing conditions (locally, regionally, state-wide, and across the country) in an effort to help predict drought and begin mitigation actions accordingly. (77) | All | Drought.gov and the U.S. Drought Monitor serve as a clearinghouse for drought-related information across the U.S. and in each state. New monitoring and assessment tools continue to be introduced, expanding their usefulness for all water use sectors. | **Drought.gov** https://www.drought.gov/<br><br>**U.S. Drought Monitor** https://droughtmonitor.unl.edu/ | 6-Improving Monitoring | Improve resilience<br><br>Reduce impact/damages | All | Missouri Department of Natural Resources<br><br>Local Groups and Entities (Cities, Counties, Utilities) |

| **Category** | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| **Subcategory** | Monitoring | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Monitor NOAA's Climate Prediction Center's Monthly Drought Outlook and Seasonal Drought Outlook to gain insight into large-scale drought outlook and trends in an effort to predict when drought impacts may begin in Missouri. (78) | All | These outlooks can help predict drought and/or drought conditions in advance which allows for greater time for other mitigation actions to be utilized. Staying aware of changing conditions in surrounding states can also benefit drought planning efforts in Missouri if drought is spreading from another state/region. | **NOAA's Climate Prediction Center** https://www.cpc.ncep.noaa.gov/products/Drought/ | 6-Improving Monitoring | Improve resilience<br><br>Reduce impact/damages | All | Regulatory Agencies<br><br>Local Groups and Entities (Cities, Counties, Utilities) |
| Make use of more recent and experimental drought forecasting tools (4-Week Evaporative Demand Drought Index Forecast, QuickDri and Potential Flash Drought) on the Drought.gov website to monitor when conditions favor upcoming droughts. Routinely check to see if new or refined products are available. (79) | All | The Evaporative Demand Drought Index (EDDI) is an experimental drought monitoring and early warning guidance tool. It examines how anomalous the atmospheric evaporative demand (also known as "the thirst of the atmosphere") is for a given location and across a time period of interest. This experimental subseasonal EDDI forecast shows projected evaporative demand for the next 28 days with 4 km gridded resolution.<br><br>The Potential Flash Drought tool was developed to improve the ability to predict flash drought. The tool calculates a rapid change index (RCI) that is the accumulated magnitude of moisture stress changes occurring over multiple weeks. Drought is likely to occur when RCI is negative. Flash drought is more likely to occur when there is a large decrease in the RCI 7-day average for a given area. | **Outlook and Forecast tools** https://www.drought.gov/forecasts/data<br><br>**Potential Flash Drought Development Map** https://www.cpc.ncep.noaa.gov/products/Drought/Flash_Drought/potential_development.php<br><br>**QuickDRI** https://quickdri.unl.edu/ | 6-Improving Monitoring | Improve resilience<br><br>Reduce impact/damages | All | Regulatory Agencies<br><br>Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Monitoring | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | The Quick Drought Response Index (QuickDri) is a shorter-term indicator of dryness that provides a snapshot of conditions of the past 4 weeks and serves as an indicator of emerging or rapidly drought conditions. It combines several hydrologic and vegetation-related indicators.<br><br>These tools can help predict drought and/or drought conditions in advance which allows for greater time for other mitigation actions to be utilized. Increased awareness among impacted stakeholders can potentially reduce impacts of future droughts with adequate planning and advanced notice. | | | | | |
| Water managers, utilities, and major water users should monitor NOAA's Climate Prediction Center's Temperature and Precipitation Outlooks to help predict if temperature, precipitation, or both are expected to be above or below normal. (80) | All | Temperature and precipitation outlooks are available at a variety of timescales. Outlooks are presented as the percent chance of above normal or below normal temperature or precipitation for a given area. Interactive maps are also available for some products that allow the user to view the outlook for a specific location along with more detailed statistics related to the outlook.<br><br>These outlooks can help provide insight into the expected future weather conditions in Missouri that contribute directly to drought (i.e., | **Available at:** https://www.cpc.ncep.noaa.gov/ | 6-Improving Monitoring | Improve resilience<br><br>Reduce impact/damages | All | Missouri Department of Natural Resources<br><br>Local Groups and Entities (Cities, Counties, Utilities) |

MISSOURI DEPARTMENT OF NATURAL RESOURCES
Missouri Geological Survey

| Category | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Monitoring | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | temperature and rainfall). Used in conjunction with other drought prediction and monitoring tools, can help predict drought and/or drought conditions in advance, allowing for better mitigation and response. | | | | | |
| Monitor NOAA's Climate Prediction Center's Soil Moisture Outlooks to track soil moisture levels ahead of and during drought. (81) | All | Soil moisture outlooks are based on calculated results from a soil moisture model. Results are presented in millimeters and translate to the amount of water present in a depth of one meter of soil. Outlooks can be compared to average soil moisture values to determine if above or below normal soil moisture is expected.<br><br>These outlooks can help provide insight into the expected soil moisture conditions in Missouri. Used in conjunction with other drought prediction and monitoring tools, can help predict drought and/or drought conditions in advance, allowing for better mitigation and response. | **Soil Moisture Outlook** https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Outlook/CAS/SM.shtml<br><br>**Current Soil Moisture map** https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst.shtml | 6-Improving Monitoring | Improve resilience<br><br>Reduce impact/damages | All | Missouri Department of Natural Resources<br><br>Missouri Department of Agriculture |

| Category | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Monitoring | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| Maintain and expand the groundwater well observation network. Expand the network to fill data gaps where significant local or regional water level declines are expected or observed, and where impacts have occurred following previous droughts. (82) | All | Improved data and information collection of groundwater resources will better support decision-making and future water planning. | **USGS Current Water Data for Missouri** https://waterdata.usgs.gov/mo/nwis/rt<br><br>**USGS National Water Information System: Mapper** https://maps.waterdata.usgs.gov/mapper/index.html | | Reduce susceptibility | All | Missouri Department of Natural Resources |
| Monitor the National Soil Moisture website to increase awareness of soil moisture levels and help determine when drought conditions are appearing or worsening. (118) | Agriculture | The National Soil Moisture website provides gridded soil moisture products derived from a variety of data sources. The information is combined to create comprehensive data products for the U.S. with various soil depths and types of data modeling. | **National Soil Moisture website** http://nationalsoilmoisture.com/index.html<br><br>**Drought.gov - NationalSoilMoisture.com** https://www.drought.gov/data-maps-tools/nationalsoilmoisturecom | 6-Improving Monitoring | Reduce impact/damages | All | Missouri Department of Agriculture<br><br>Missouri Department of Natural Resources |
| Monitor NASA's current soil moisture data to increase awareness of soil moisture levels and help determine when drought conditions are appearing or worsening. (119) | Agriculture | NASA's Short-term Prediction and Transition Center - Land Information System (SPoRT-LiS) provides high-resolution gridded soil moisture products in real-time to support modeling and improve situational awareness. The model is updated every six hours and provides data at approximately 3 km resolution which is more detailed than most other sources. | **Drought.gov - NASA SPoRT-LiS Soil Moisture Products** https://www.drought.gov/data-maps-tools/nasa-sport-lis-soil-moisture-products<br><br>**NASA Short-term Prediction Research and Transition Center** | 6-Improving Monitoring | Reduce impact/damages | All | Missouri Department of Agriculture<br><br>Missouri Department of Natural Resources |

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| **Category** | Education - Data |
| **Subcategory** | Monitoring |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| | | Data produced by NASA include 20-, 40-, 100-, and 200-centimeter soil moisture percentile data. The 0–100 cm soil moisture percentile data has shown utility for drought monitoring. The near-surface (0–10 cm) layer responds quickly to heavy precipitation and rapidly drying events. In deeper layers, soil moisture evolves more slowly and has demonstrated greater utility overall for drought monitoring purposes since drought evolves typically on timescales of weeks to years. | https://weather.msfc.nasa.gov/sport/ | | | | |

| **Category** | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| **Subcategory** | Planning | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| After a drought event, evaluate the effectiveness of mitigation efforts undertaken prior to the drought and any possible adjustments that might improve the effectiveness of the mitigation action for the next drought event. (85) | All | Allows residents, local governments, and state agencies to improve drought mitigation and response for future drought events. Improves efficiency in local and state agency response actions by eliminating actions that do not help in preparing for drought or significantly reduce impacts from drought. | **Missouri's 2018 Drought Response Report is an example after-drought report.** https://dnr.mo.gov/document-search/2018-missouri-drought-numbers-pub2747 | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>Missouri Department of Agriculture<br><br>Local Groups and Entities (Cities, Counties, Utilities) |
| Study impacts to water quality resulting from wildfires, reduced stream flow, and lower lake levels. (86) | Environment | Wildfire, reduced stream flows, and lower lake levels are all possible impacts of drought and themselves can have impacts on water quality. Future projections of rainfall indicate heavier precipitation events which increases pollution from surface run-off and creates water quality issues during times of drought and low-flow conditions. Studying the interactive effects of drought on water quality can help better quantify economic damages from drought and potentially identify mitigation actions that minimize impacts to water quality. | **Wildfires: How Do They Affect Our Water Supplies?** https://www.epa.gov/sciencematters/wildfires-how-do-they-affect-our-water-supplies<br><br>**Water Quality After Wildfire** https://www.usgs.gov/mission-areas/water-resources/science/water-quality-after-wildfire | 6-Improving Monitoring | Improve resilience | All | Missouri Department of Natural Resources, Division of Environmental Quality |

| **Category** | Education - Data |
|---|---|
| **Subcategory** | Planning |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Perform data collection and analysis of the impacts on private (domestic) water supplies from drought. Determine standardized method of analysis to ensure information is useful, can be analyzed over a period of several years, and assessed over different drought events. (87) | Municipal | This action provides more information on the true extent of drought impacts and can inform state agencies on potential strategies that could help improve the resilience of those served by private (domestic) wells. | | 6-Improving Monitoring | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources |

| Category | Education - Data | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Planning | | | | | | |
| Applicable Drought Phase | Phase 1 – Incipient Drought | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Disseminate information from drought forecasting tools (such as NOAA's Climate Prediction Center's Monthly and Seasonal Drought Outlooks, 4-Week Evaporative Demand Drought Index Forecast and Potential Flash Drought) to agricultural producers, livestock producers, state agencies, local governments, and other stakeholders when indications of future drought are likely. (83) | Agriculture | Potentially reduce the impacts of drought on agricultural sector by providing timely information for proper mitigation actions to be enacted. It is also important to make sure that the agricultural sector is aware of forecasting and prediction tools available to them, well before droughts occur. | **NOAA's Climate Prediction Center** https://www.cpc.ncep.noaa.gov | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages | All | Missouri Department of Natural Resources<br><br>Missouri Department of Agriculture |
| Disseminate public health information on diseases related to poor air and water quality and vector-borne illnesses. Provide information to the public on the variety of potential health concerns caused by drought and potential mitigation actions. (84) | All | Dissemination of public health information can help prevent disease and/or the severity of outbreaks of disease caused by air and water quality issues and/or vector-borne illnesses from drought. | **Centers for Disease Control and Prevention (CDC)** https://www.cdc.gov/nceh/drought/implications.htm)<br><br>**Drought.gov website** https://www.drought.gov/sectors/public-health) | 2-Increasing Public Awareness | Improve resilience<br><br>Reduce impact/damages | All | Missouri Department of Health and Senior Services<br><br>Missouri Department of Natural Resources |

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| **Category** | Education - Data |
| **Subcategory** | Policy |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| The Department of Agriculture should support agricultural research through the University of Missouri Extension and other state universities focusing on drought tolerant species. (88) | Agriculture | Research could identify new species of drought tolerant plants that could perform better in water-stressed conditions, thus reducing the impact of drought on the agriculture sector. These species could reduce the water demand of farmers which increases water supply available to other users. | **University of Missouri - College of Agriculture, Food & Natural Resources** https://cafnr.missouri.edu/2019/08/research-center-magazine-battling-drought/<br><br>**Drought Tolerance of Soybean Crops in Missouri** https://www.researchgate.net/publication/262183793_Drought_Tolerance_of_Soybean_Crops_in_Missouri | 1-Reducing Impacts | Reduce impact/damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central<br>Central | Missouri Department of Agriculture<br><br>University of Missouri, Department of Agriculture |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Assistance | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Conduct water audits or provide water audit training to commercial and industrial users. (39) | Industrial | Industrial and commercial water audits can identify water saving opportunities in association with cost savings. | **US EPA WaterSense**<br>https://www.epa.gov/watersense<br>https://www.epa.gov/sites/default/files/2017-02/documents/watersense-at-work_final_508c3.pdf<br><br>**The Alliance for Water Efficiency**<br>https://www.allianceforwaterefficiency.org/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>Local Groups and Entities (Cities, Counties, Utilities) |
| Provide grants for improving leak control efforts and water metering. (40) | Municipal | Smaller water providers may need financial assistance with leak detection, metering and meter replacement, line replacement, and other actions to reduce water system loss. | **Missouri Rural Water Association**<br>https://moruralwater.org/<br><br>**Missouri DNR Infrastructure Funding Toolkit**<br>https://oa2.mo.gov/ARPAtoolkits/water-infrastructure<br><br>**EPA Drinking Water Grants**<br>https://www.epa.gov/ground-water-and-drinking-water/drinking-water-grants<br><br>**USDA Emergency Community Water Assistance Grants in Missouri**<br>https://www.rd.usda.gov/programs-services/water-environmental-programs/emergency-community-water-assistance-grants/mo | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>Missouri Rural Water Association<br><br>Local Groups and Entities (Cities, Counties, Utilities) |

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| **Category** | Demand |
| **Subcategory** | Monitoring |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Missouri Department of Agriculture should provide information on soil moisture monitoring and measurements and methods to improve soil moisture retention, such as aeration and mulching. Provide soil moisture meters and incentives for soil enhancement. (41) | Agriculture | Understanding soil moisture for irrigation scheduling can prevent over-watering and under-watering, increase crop yield, and help farmers mitigate drought conditions as they start to occur. | **Missouri Extension Tools for Monitoring Soil Moisture:** https://extension.missouri.edu/programs/irrigation/tools-for-monitoring-soil-moisture<br><br>**Missouri Extension Improving Lawn and Landscape Soils**: https://extension.missouri.edu/publications/g6955<br><br>**Missouri Extension Home Lawn Watering Guide:** https://extension.missouri.edu/publications/g6720<br><br>**NIDIS National Coordinated Soil Moisture Monitoring Network** https://www.drought.gov/drought-in-action/national-coordinated-soil-moisture-monitoring-network<br><br>**Ogallala Water - Soil Moisture Monitoring** https://ogallalawater.org/soil-moisture-monitoring/<br><br>**be water wise - Soil Moisture Rebates** https://socalwatersmart.com/en/residential/rebates/available-rebates/soil-moisture-sensors/ | 6-Improving Monitoring | Reduce impact/damages<br><br>Reduce susceptibility | Northwest<br>North Central<br>Northeast<br>West Central<br>Central<br>East Central | Missouri Department of Agriculture |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Policy | | | | | | |
| Applicable Drought Phase | Phase 3 – Conservation | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Temporarily suspend the reduced water rates provided to large water users. (116) | Municipal | Discourages excessive water use. If water use is not reduced, the increased revenue can be used to fund water conservation programs or offset costs of securing alternate supplies. | **2012 Missouri Drought Response Report** https://dnr.mo.gov/document-search/2012-missouri-drought-report | 4-Promoting Water Conservation | Improve resilience | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Develop livestock water system for less reliance on ponds. Design and install a livestock watering system sufficient for the size of the herd with water from a clean and reliable source. (42) | Agriculture | 'Provides adequate and reliable water for livestock needs that is not rainfall dependent. These systems can be designed for rotational grazing and keeps livestock out of streams which improves water quality. | **Missouri Extension: Pumps and Watering Systems for Managed Beef Grazing**: https://extension.missouri.edu/publications/eq380<br><br>**NRCS video**: https://www.youtube.com/watch?v=_RdXuRD2UmU | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | Northeast<br>West Central<br>Central<br>Southwest | Missouri Department of Agriculture<br><br>University of Missouri, Cooperative Extension Service<br><br>Regulatory Agencies |
| Conduct water audits of agricultural irrigation systems and implement | Agriculture | Irrigation systems, especially center-pivot systems may use excessive | **Missouri Extension: Crop Water Use Program for Irrigation** | 4-Promoting Water Conservation | Reduce impact/damages | Northwest<br>North Central | Missouri Department of Agriculture |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| measures to improve water use efficiency. (43) | | amounts of water, apply water unevenly, or rely on end-guns that result in significant water loss to evaporation. Conducting water audits and performing measures, such as sprinkler nozzle retrofits will reduce water demand, and also reduce energy usage and cost due to lower pumping requirements. Water audits of center pivot systems often result in demand reductions of approximately 15%. | https://extension.missouri.edu/publications/mp800<br><br>**2021 Florida State Statute 570.93 establishing an agricultural water conservation program that includes a cost-share program and voluntary interim measures or BMPs which provide for increased efficiencies in the use and management for agricultural production.** http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0500-0599/0570/Sections/0570.93.html | | Reduce susceptibility | Northeast<br>West Central<br>Central | University of Missouri, Cooperative Extension Service |
| State legislature creates tax credit incentives for efficient water use. Provide state tax credit for installation of qualifying appliances and fixtures. (44) | All | Helps increase the rate of high-efficiency appliance and fixture adaptation among customers. Improves public response to water conservation since the costs are offset by government tax credits. | **Consortium of Energy Efficiency standards include water efficiency standards for residential clothes, commercial dishwashers, ice machines and commercial clothes washers. Credits can be provided for appliances that meet these standards**: https://cee1.org/content/cee-program-resources | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Promote water-friendly landscaping and planting of drought- resistant lawns. Encourage the use of native landscape materials that have minimum watering requirements. (48) | Municipal | Water-friendly landscaping reduces landscape water requirements. These techniques can provide attractive landscapes with native plants that perform better in drought conditions than non-native | **Missouri Extension: Water-Efficient Gardening and Landscaping:** https://extension.missouri.edu/publications/g6912<br><br>**H2ouse - Lawn Plant Materials** | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Missouri Department of Natural Resources<br><br>Missouri Department of Agriculture |

| Category | Demand | | | | | | |
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| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | plants. These plantings may have ecological benefits as well. | https://www.h2ouse.org/lawn-plant-materials/<br><br>**City of Columbia (MO) Outside Water Conservation**<br>https://www.como.gov/utilities/columbia-power-partners/water-conservation/outside-water-conservation/<br><br>**Univ. of Georgia - Water-wise Landscape Guide**<br>http://northgeorgiawater.org/wp-content/uploads/2016/01/MDC_WaterWise_Landscape_Final-7MB.pdf<br><br>**Missouri Department of Conservation - Conservation Planning Tools for Missouri Communities: Reference Guide**<br>https://mdc.mo.gov/sites/default/files/2020-04/Conservation%20Planning.pdf | | | | Missouri Department of Conservation, Community Conservation Program |
| Support economic incentives for individual investment in conservation including reduced lawn watering and irrigation maintenance. (49) | Municipal | Economic incentives encourage water conservation and increase the rate of adoption of high-efficiency irrigation equipment and methods among farmers and homeowners. The Missouri Soil and Water Conservation Cost-Share Program offers financial incentives for irrigation | **Missouri Department of Natural Resources - Soil and Water Conservation Cost-Share Practices**<br>https://dnr.mo.gov/land-geology/businesses-landowners-permittees/financial-technical-assistance/soil-water-conservation-cost-share-practices | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Missouri Department of Natural Resources |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | water conveyance, irrigation system sprinklers and nozzles, tail water recovery, and other best management practices related to irrigation, water efficiency, and environmental protection. | | | | | |
| Encourage Qualified Water Efficient Landscaper (QWEL) professional certification. (50) | Municipal | The Qualified Water Efficient Landscaper (QWEL) program is an EPA WaterSense labeled professional certification in irrigation system audits. QWEL certified professionals are trained in efficient irrigation principles and sustainable landscaping practices. A QWEL certified professional can use water efficiently in a landscape, reduce runoff and overspray, select and install the most efficient irrigation equipment, and develop an irrigation schedule and program the irrigation controller accordingly. | **Qualified Water Efficient Landscaper website:** https://www.qwel.net/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Implement and maintain a water efficiency and water loss control program. Water utilities should routinely conduct leak detection, fix leaks, | Municipal | Reducing water loss from a utility distribution system helps to meet increasing demands without a new source of supply. Reducing water loss also provides | **Since 2010, Georgia has required public water systems serving over 3,300 people meet the requirements of the Water Stewardship Act of 2010. The requirements include (1)** | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| replace old infrastructure, limit process water losses, and track non-revenue water loss. (53) | | financial benefits for a utility. Tracking of non-revenue water allows a utility to better understand their losses over time and develop a plan to minimize losses through line repairs and replacements as necessary. | **completing an annual water loss audit; (2) developing and implementing a water loss control program; (3) developing water efficiency goals; and (4) demonstrating progress to improving water supply efficiency.** https://epd.georgia.gov/watershed-protection-branch/water-efficiency-and-water-loss-audits<br><br>**American Water Works Association - Water loss Control** https://www.awwa.org/Resources-Tools/Resource-Topics/Water-Loss-Control | | | | Missouri Department of Natural Resources<br><br>Missouri Rural Water Association |
| Establish leak and minor plumbing repair program for low-income households. Fund programs to have certified plumbers identify and repair leaks for qualifying customers. (54) | Municipal | Low-income households face higher financial barriers to repair leaks and fix plumbing issues. Therefore, water loss or inefficiently operating fixtures increases water waste and customer water bills. A low-income repair program helps eliminate the financial barriers for repairs that could improve water efficiency through eliminating leaks. | **San Antonio Water System - Plumbers to People program**: https://apps.saws.org/Conservation/CaseStudies/docs/P2P_20120402_.pdf<br><br>**San Antonio Water Systems - Uplift program** https://uplift.saws.org/helping-neighbors-in-need/<br><br>**EPA - Drinking Water And Wastewater Utility Customer Assistance Programs** https://www.epa.gov/sites/default/files/2016-04/documents/dw-ww_utilities_cap_combined_508.pdf | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

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| **Category** | Demand |
| **Subcategory** | Water Efficiency |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Install advance metering infrastructure (AMI) systems with smart meters, communication networks and data management systems that provide a customer portal with potential leak alerts and provide system operators with potential system leak alerts. (55) | Municipal | AMI systems improve water conservation by alerting customers to leaks and informing customers of their water use behaviors which can lead to changes in water use patterns. Utilities can identify system-side leaks faster as well, further reducing losses to non-revenue water and saving large volumes of water by repairing leaks faster than under normal conditions. | **What is Advanced Metering Infrastructure (AMI)?** https://www.wwdmag.com/what-articles/what-advanced-metering-infrastructure-ami<br><br>**Unearthing the Hidden Benefits of Advanced Metering Infrastructure (AMI)** https://internetofwater.org/data-stories/return-on-investment/unearthing-the-hidden-benefits-of-advanced-metering-infrastructure-ami/<br><br>Meters may be eligible for funds from FAC or other funding agencies.<br>**Missouri Department of Natural Resources – Financial Assistance Center**. Drinking water funding opportunities: https://dnr.mo.gov/water/business-industry-other-entities/financial-opportunities/financial-assistance-center/drinking-water | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |
| Adopt an ordinance that would prohibit wasting water from sources such as customer leaks, runoff from driveways and sidewalks, or irrigation overspray. (57) | Municipal | Irrigation systems often leak or overspray resulting in water flowing in a gutter, ditch, or storm drain. This type of ordinance can be monitored by a municipal employee that looks for wasteful watering behaviors in irrigation | **San Antonio Water System - Water Waste and Conservation Ordinance example:** https://www.saws.org/conservation/water-waste/<br>https://www.saws.org/conservation/conservation-ordinance/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | systems in the same manner that other municipal ordinances are monitored (e.g., citizen complaints, water department employees' observations while performing meter reading or maintenance work, municipal employee driving through neighborhoods to check for ordinance violations, etc.). | | | | | |
| Establish year-round lawn and landscape irrigation schedules (with set time of day and/or days per week). (59) | Municipal | Rather than set irrigation schedules during drought or emergency conditions, some water providers have implemented year-round or seasonal irrigation schedules. Schedules are typically 2 or 3 days per week staggard by odd/even house numbers, and with prohibited irrigation during the hot part of the day (e.g., 9 am - 6 pm). | **University of Missouri Extension - Home Lawn Watering Guide:** https://extension.missouri.edu/publications/g6720<br><br>**EPA Watering Tips**: https://www.epa.gov/watersense/watering-tips | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Establish annual irrigation inspections for automatic sprinkler and irrigation systems that includes leak detection, check of equipment functionality, and proper irrigation volumes applied to landscape. | Municipal | Water providers can provide professional landscape irrigation audits that identify leaking or broken equipment and provide recommendations for system improvements such as efficient spray heads, better timing of | EPA Irrigation with a Pro: https://www.epa.gov/watersense/irrigation-pro<br><br>EPA - Guidelines for Irrigation Audits on WaterSense Labeled New Homes: | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Provide landscape irrigation audits by certified professionals. (60) | | watering, and redesign of irrigation system layout. | https://www.epa.gov/sites/default/files/2017-01/documents/ws-homes-irr-audit-guidelines.pdf | | | | |
| Promote the adoption of local building, plumbing, landscaping or other codes that specify water and energy efficiency standards required for new construction, irrigation systems or landscaping through state law or local ordinance. (61) | Municipal | Local or state ordinances can require water efficiency standards for new construction or remodeling that are more stringent than national standards for plumbing fixtures. Limitations can be provided on the area of irrigated landscape with requirements for water efficient irrigation technology. | Alliance for Water Efficiency - Net Blue Water-Neutral Growth https://www.allianceforwaterefficiency.org/resources/topic/net-blue-supporting-water-neutral-growth<br><br>Sustainable Development Code - Water Efficiency Standards for New Construction: https://sustainablecitycode.org/brief/water-efficiency-standards-for-new-construction-4/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Require leak inspections and repairs and that water fixtures and equipment meet efficiency standards prior to property resale or lease. (62) | Municipal | Water leaks and inefficient water fixtures wastewater. An ordinance can be enacting requiring a water audit and resulting repairs with water efficient fixtures prior to sale of a property. | **Retrofit on Resale Ordinances** https://verderiver.org/retrofit-on-resale-ordinances/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Provide incentives for residential customers to improve water use efficiency in the home. Set up rebate, distribution or installation programs for WaterSense or ENERGY STAR certified high-efficiency toilets, clothes washers, shower heads, | Municipal | Provides homeowners incentives to be water efficient. | **EPA WaterSense at Work** https://www.epa.gov/watersense<br><br>**Consortium of Energy Efficiency standards include water efficiency standards for residential clothes, commercial dishwashers, ice machines and commercial clothes washers. Credits can be provided for** | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| water heaters, irrigation technology or other water-saving appliances. (63) | | | **appliances that meet these standards:**<br>ttps://cee1.org/content/cee-program-resources<br><br>**City of Columbia (MO) - toilet rebate**<br>https://www.como.gov/utilities/columbia-power-partners/water-conservation/efficient-flush-rebate/<br><br>**City of Columbia (MO) - irrigation rebate**<br>https://www.como.gov/utilities/columbia-power-partners/water-conservation/d-r-i-p-irrigation-rebate/<br><br>**Arnold (MO) - toilet rebate**<br>https://www.arnoldmo.org/download/water-conservation-low-flow-toilet-rebate-program/<br><br>**Be water wise - rebates**<br>https://socalwatersmart.com/en/residential/rebates/available-rebates/available-rebates-overview/<br><br>**San Antonio Water System - rebates**<br>https://www.saws.org/conservation/residential-outdoor-programs-rebates/ | | | | |

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| **Category** | Demand |
| **Subcategory** | Water Efficiency |
| **Applicable Drought Phase** | Drought Advisory |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Provide incentives for commercial customers to improve water use efficiency in businesses. Set up rebate, distribution, or installation programs for WaterSense or ENERGY STAR certified high-efficiency urinals, commercial dishwasher systems or pre-rinse spray valves, ice machine replacement or similar appliances. (64) | Municipal | Provides business owners incentives to be water efficient. | **EPA WaterSense at Work** https://www.epa.gov/sites/default/files/2017-02/documents/watersense-at-work_final_508c3.pdf<br><br>**Consortium of Energy Efficiency standards include water efficiency standards for commercial dishwashers, ice machines and commercial clothes washers. Credits can be provided for appliances that meet these standards:** https://cee1.org/content/cee-program-resources<br><br>**Be Water Wise.com** https://socalwatersmart.com/en/commercial/rebates/available-rebates/commercial-devices/<br><br>**San Antonio Water System rebate programs** https://www.saws.org/conservation/commercial-programs-rebates/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Provide cooling tower audits by certified professionals. (65) | Municipal | Water use among cooling towers can be reduced by pre-treatment, installation of conductivity controllers, pH meters, make-up and blowdown meters, etc. | **EPA WaterSense at Work** https://www.epa.gov/sites/default/files/2017-02/documents/watersense-at-work_final_508c3.pdf<br><br>**Federal Energy Management Program: Cooling Tower Management** | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | West Central<br>Central<br>East Central | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Demand | | | | | | |
|---|---|---|---|---|---|---|---|
| **Subcategory** | Water Efficiency | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| | | | https://www.energy.gov/eere/femp/best-management-practice-10-cooling-tower-management<br><br>**San Antonio Water System - Cooling Tower Program**<br>https://www.saws.org/conservation/commercial-programs-rebates/cooling-tower-program/ | | | | |
| Set up a commercial vehicle washing and car wash system replacement program that provides financial incentives to replace leaking and/or inefficient equipment that can save water or the installation of water recycling equipment that allows water to be reused for multiple washes. (66) | Municipal | Car wash facilities can lose water through leaking spray nozzles and hoses. Car washes can recycle 50% of water or more with proper design and maintenance. | **EPA WaterSense at Work**<br>https://www.epa.gov/sites/default/files/2017-02/documents/watersense-at-work_final_508c3.pdf<br><br>**International Carwash Association - Water Savers**<br>https://www.carwash.org/watersavers/about/water-savers-criteria<br><br>**State of Georgia - Carwash Certification**<br>http://rules.sos.state.ga.us/gac/391-3-31<br><br>**San Antonio Water System - car wash program**<br>https://sawsstg.saws.org/conservation/commercial-programs-rebates/watersaver-car-wash-program/ | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | West Central<br>Central<br>East Central | Local Groups and Entities (Cities, Counties, Utilities) |
| Implement a water conservation rate structure such as a uniform block or an | Municipal | Conservation rate structures are designed with the goals of (1) reducing water consumption without | **EDF White Paper on Conservation Rate Structures:**<br>http://blogs.edf.org/energyexchange/files/2017/12/conservation-rates-white-paper-Final.pdf | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

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| **Category** | Demand | | | | | | |
| **Subcategory** | Water Efficiency | | | | | | |
| **Applicable Drought Phase** | Drought Advisory | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| increasing block rate structure. (56) | | negatively impacting utility revenues; (2) rewarding customers for installing water efficient appliances and for behaviors that result in less water use; and (3) targeting inefficiency in discretionary water uses such as landscape irrigation. This action will reduce water use both before and during a drought, and by lowering demand, extend the supply. | **American Water Works Association - Manual M1 on water rates, fees and charges.** https://engage.awwa.org/PersonifyEbusiness/Store/Product-Details/productId/63111199 | | | | |

| Category | Demand | | | | | | |
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| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Phase 1 – Incipient Drought | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
| Promote voluntary restrictions on water use. As a component of this, provide tips on reducing water use and request that customers restrict non-essential water use. (46) | Municipal | Water users need information on how to be more efficient in order to save water. Identifying non-essential water uses helps customers identify water saving opportunities and may achieve 5-10% reduction in water use in communities with high base water use. | **Alliance for Water Efficiency: Use and Effectiveness of Municipal Irrigation Restrictions During Drought:** https://www.allianceforwaterefficiency.org/files/assets/Final%20AWE%20Use%20%26%20Effectiveness%20of%20Municipal%20Irrigation%20Restrictions%20During%20Drought-Executive%20Summary-January%202020.pdf | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |
| Establish a minimum number of cycles of concentration for cooling towers. (58) | Municipal | Water use among cooling towers can be reduced by pre-treatment, installation of conductivity controllers, pH meters, make-up and blowdown meters, etc.<br><br>Cooling tower water use is a major water user in office buildings, hospitals, schools, institutional facilities, and grocery stores. | **EPA WaterSense at Work** https://www.epa.gov/sites/default/files/2017-02/documents/watersense-at-work_final_508c3.pdf<br><br>**Federal Energy Management Program: Cooling Tower Management** https://www.energy.gov/eere/femp/best-management-practice-10-cooling-tower-management<br><br>**San Antonio Water System - Cooling Tower Program** https://www.saws.org/conservation/commercial-programs-rebates/cooling-tower-program | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | West Central<br>Central<br>East Central | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Missouri Department of Natural Resources |

| Category | Demand | | | | | | |
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| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Phase 2 – Drought Alert | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Limit main flushing as much as possible, while still meeting all regulatory requirements. (52) | Municipal | Main flushing can use significant amounts of water. Limiting main flushing to the minimum amount required for efficient operations and meeting regulatory requirements can potentially limit the amount of water used for this purpose, which is technically a non-revenue water use. | American Water Works Association M36 Water Audits and Water Loss Control Programs | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Missouri Department of Natural Resources |

| Category | Demand | | | | | | |
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| Subcategory | Water Efficiency | | | | | | |
| Applicable Drought Phase | Phase 3 – Conservation | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| Establish water rate drought surcharges on water use during drought conditions. (45) | Municipal | Surcharges discourage excessive water use during drought conditions or applies surcharges to those willing to pay more for not reducing water use. They also provide additional revenue to the utility during times of lower water use and to offset cost of emergency water supply. | **AWWA M1 Principles of Water Rates, Fees and Charges - Chapter 3 Drought and Surcharge Rates:** https://www.awwa.org/portals/0/files/publications/documents/samples/M1WaterRates-ChV3.pdf<br><br>**Taylor (Texas) Drought Contingency Ordinance mandates limits water use per household under Stage 5 conditions with surcharges ranging from $25 to $100 per 1,000 gallons used over the allotment.** https://library.municode.com/tx/taylor/ordinances/code_of_ordinances?nodeId=966933 | 4-Promoting Water Conservation | Improve resilience<br><br>Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Missouri Public Service Commission |

| **Category** | Demand | | | | | | |
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| **Subcategory** | Water Efficiency | | | | | | |
| **Applicable Drought Phase** | Phase 3 – Conservation | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Stakeholders** |
| In response to dwindling supply, implement mandatory restrictions on water use. As a component of this, provide tips on reducing water use and warn, then fine, customers who do not restrict non-essential or prohibited water use. (47) | Municipal | Water users need information on how to be more efficient in order to save water and to understand penalties for excessive water use during times of mandatory restrictions. This action may achieve a 10-20% reduction in water use in communities with high base water use. | **Alliance for Water Efficiency: Use and Effectiveness of Municipal Irrigation Restrictions During Drought**: https://www.allianceforwaterefficiency.org/sites/www.allianceforwaterefficiency.org/files/assets/Final%20AWE%20Use%20%26%20Effectiveness%20of%20Municipal%20Irrigation%20Restrictions%20During%20Drought-Executive%20Summary-January%202020.pdf<br><br>**Palmyra, Missouri:** https://ecode360.com/28357834<br><br>**Pflugerville, Texas:** https://utilitybilling.pflugervilletx.gov/water-conservation/mandatory-water-conservation | 4-Promoting Water Conservation | Reduce impact/damages<br><br>Reduce susceptibility | All | Local Groups and Entities (Cities, Counties, Utilities) |

| Category | Demand |
|---|---|
| Subcategory | Water Efficiency |
| Applicable Drought Phase | Phase 4 – Drought Emergency |

| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Stakeholders |
|---|---|---|---|---|---|---|---|
| Reduce pressure throughout all or part of the distribution system, while maintaining necessary pressure for "high priority" users such as hospitals and firefighters. (51) | Municipal | Pressure management can reduce leakage, extend the life of assets, decrease energy costs, and improve customer service. During severe drought conditions system pressure can be reduced to a minimum level. | **American Water Works Association M36 Water Audits and Water Loss Control Programs**<br><br>**American Water Works Association Pressure Management Factsheet** https://www.awwa.org/Portals/0/AWWA/ETS/Resources/Technical%20Reports/25693%20Water%20Loss%20Control%20Pressure%20Management%20Factsheet%2011_18_2020.pdf?ver=2020-12-01-210009-973 | 4-Promoting Water Conservation | Improve resilience<br><br>Reduce impact/damages | All | Local Groups and Entities (Cities, Counties, Utilities)<br><br>Regulatory Agencies |

| **Category** | Other | | | | | | |
|---|---|---|---|---|---|---|---|
| **Subcategory** | Policy | | | | | | |
| **Applicable Drought Phase** | Phase 2 – Drought Alert | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Implementing Agency** |
| Missouri Department of Transportation can grant waivers that eliminate the fee for oversize loads so that farmers can transport wide loads of hay. Also allowing for transportation of oversized and/or overweight loads at night and during holidays. (109) | Agriculture | Hay can be in short supply during times of drought which forces livestock producers to buy hay from alternate sources. Eliminating fees and allowing for transportation of hay outside normal times decreases the impact on livestock producers, while providing logistical and scheduling relief for the agricultural community. | **2018 Missouri Drought Response Report** https://dnr.mo.gov/document-search/2018-missouri-drought-numbers-pub2747<br><br>**Missouri Department of Transportation Oversize/Overweight Regulations** https://www.modot.org/sites/default/files/documents/OSOWRule2021_0_0_0.pdf | 1-Reducing Impacts | Reduce impact/damages | All | Missouri Department of Agriculture<br><br>Missouri Department of Transportation |
| The Soil and Water Districts Commission can allow haying of cover crops to provide needed forage and waive requirement that the production crop must be a minimum of two crop rotations. (110) | Agriculture | Hay and other forage can be in short supply during drought, so this action increases the available forage available to livestock producers. Can reduce the financial impacts on livestock producers as well since the cover crops are already planted. | **2018 Missouri Drought Response Report** https://dnr.mo.gov/document-search/2018-missouri-drought-numbers-pub2747 | 1-Reducing Impacts | Reduce impact/damages | All | Missouri Department of Natural Resources |

| Category | Other | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Policy | | | | | | |
| Applicable Drought Phase | Phase 2 – Drought Alert | | | | | | |
| **Action** | **Primary Sector** | **Why is this Action Needed?** | **For More Information** | **Goals Addressed** | **Vulnerability Addressed** | **Crop Reporting Districts** | **Implementing Agency** |
| Defer the grazing school requirement so that the Soil and Water Conservation Districts can be allowed to develop contracts for water development, water distribution, and fencing. This allows the landowner up to 12 months to complete the grazing school requirement. (111) | Agriculture | Allows the Soil and Water Conservation Districts to help implement mitigation actions by eliminating time-consuming requirements for the landowner that could be an impediment to timely drought response. | **University of Missouri Extension - Forages Program** https://extension.missouri.edu/programs/forages<br><br>**Soil and Water Conservation Cost-Share Practices** https://dnr.mo.gov/land-geology/businesses-landowners-permittees/financial-technical-assistance/soil-water-conservation-cost-share-practices<br><br>**Soil and Water Conservation District information** https://mosoilandwater.land/ | 1-Reducing Impacts | Reduce impact/damages | All | Missouri Department of Natural Resources |
| Soil and Water Districts Commission can grant a variance that allows grazing in livestock exclusion areas. (113) | Agriculture | Increases the forage available from an alternate source at no additional cost to livestock producers. Can reduce the financial impacts on livestock producers. | **Soil and Water Conservation District information** https://mosoilandwater.land/ | 1-Reducing Impacts | Reduce impact/damages | All | Missouri Department of Natural Resources |

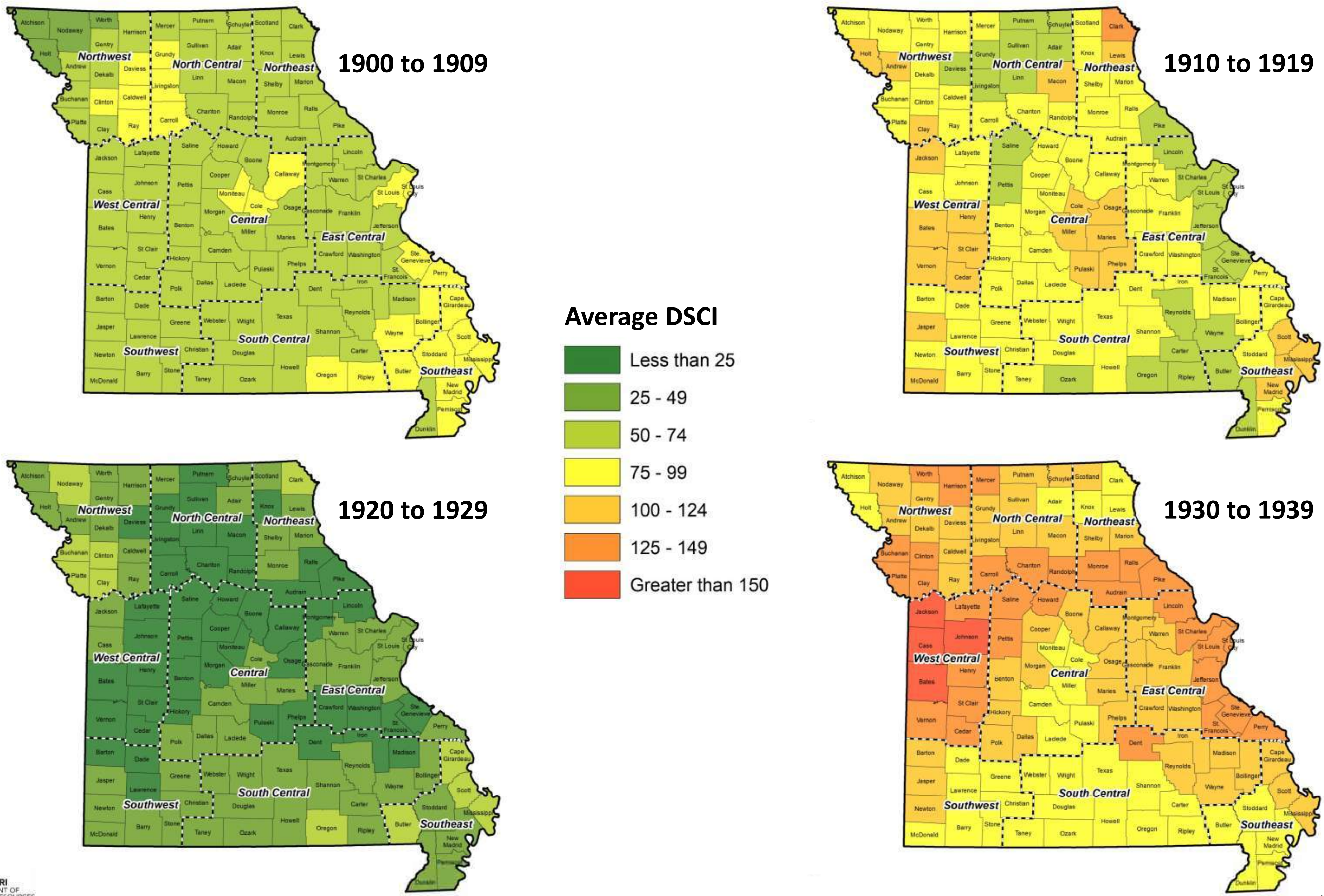
| Category | Other | | | | | | |
|---|---|---|---|---|---|---|---|
| Subcategory | Policy | | | | | | |
| Applicable Drought Phase | Phase 2 – Drought Alert | | | | | | |
| Action | Primary Sector | Why is this Action Needed? | For More Information | Goals Addressed | Vulnerability Addressed | Crop Reporting Districts | Implementing Agency |
| NRCS grants special allowance to cut hay on the grassy areas within the wetland easements. (114) | Agriculture | Increases the hay supply available either directly to the landowner if needed, or the landowner can sell the hay to farmers that need additional hay. | **2018 Missouri Drought Response Report** https://dnr.mo.gov/document-search/2018-missouri-drought-numbers-pub2747 | 1-Reducing Impacts | Improve resilience<br><br>Reduce impact/damages | All | U.S. Department of Agriculture, Natural Resource Conservation Service |

# Appendix A
# Drought Severity and Coverage Index Maps

This appendix includes maps depicting the average Drought Severity and Coverage Index (DSCI) by county for the previous 12 decades, dating back to 1900. The DSCI is an experimental method for analyzing drought data which converts drought levels from the USDM to a single numerical value for a given geographic area. The DSCI is calculated using categorical data and applying the following formula using the percentage of area covered by each drought category (i.e., D0 through D4):

$$DSCI = (1 \times D0) + (2 \times D1) + (3 \times D2) + (4 \times D3) + (5 \times D4)$$

The average DSCI was calculated for each county using historical monthly data from NIDIS for each decade based on Standardized Precipitation Index (SPI) values converted to USDM drought categories.

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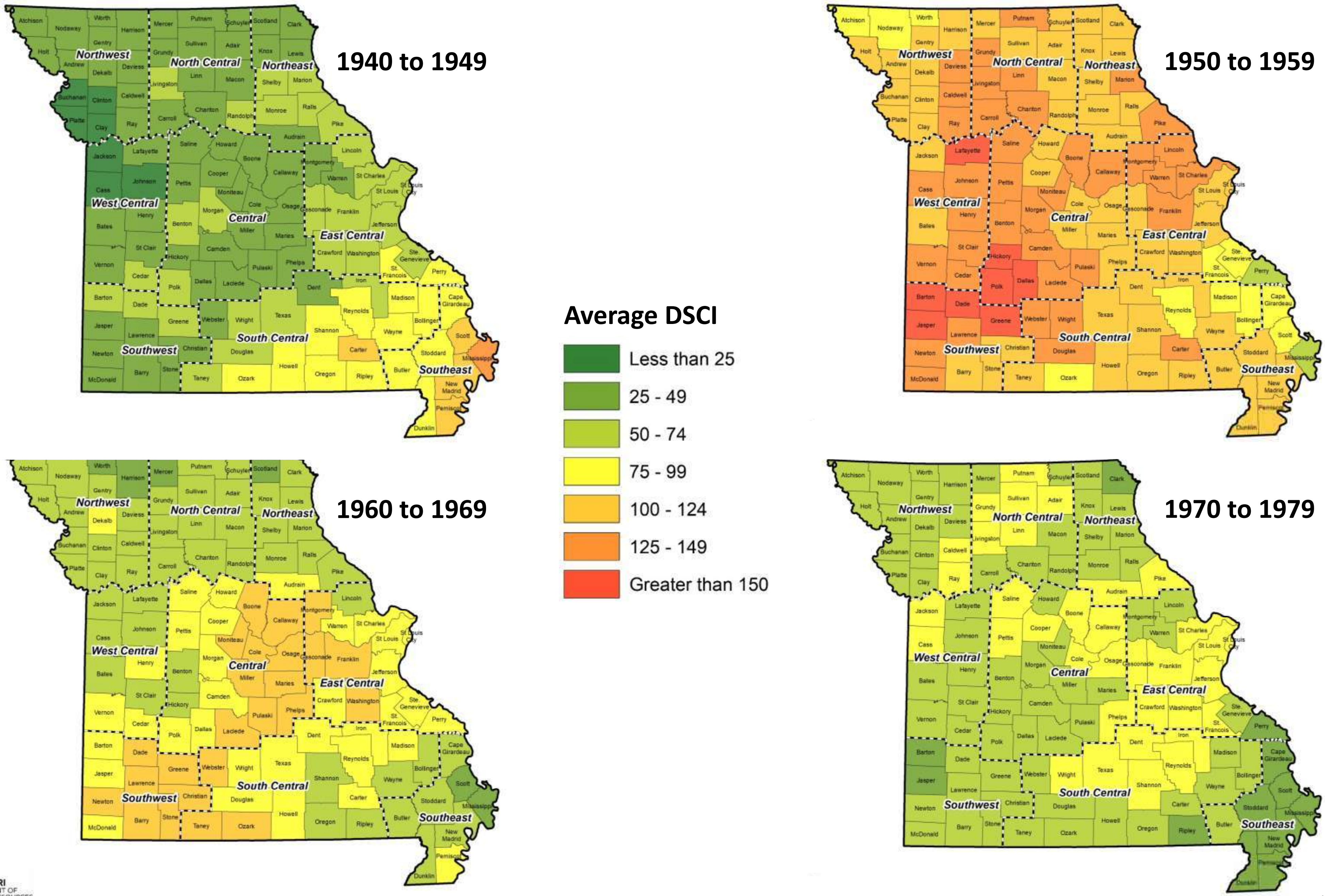


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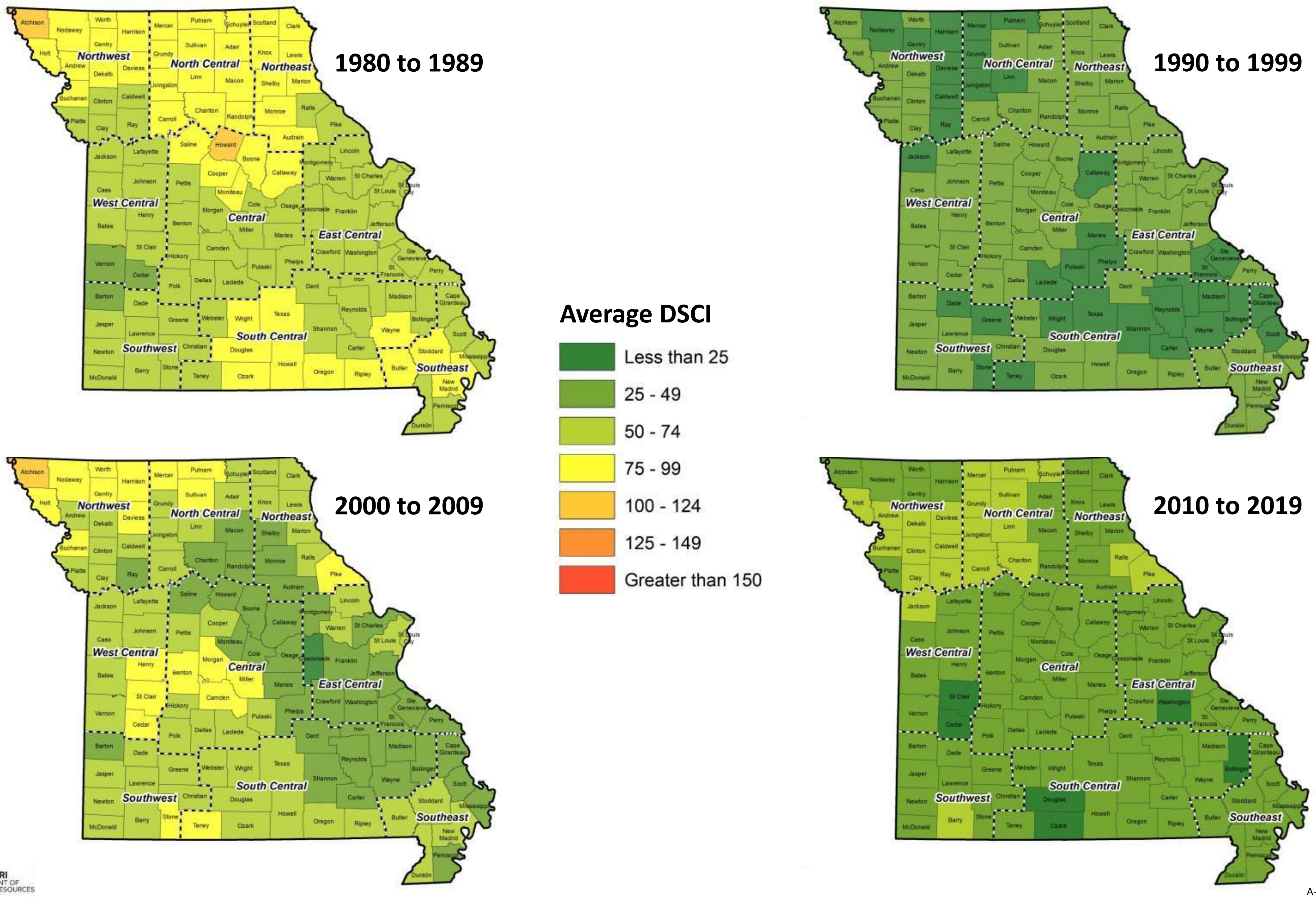


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# Appendix B
# Assessing Drought Damages and Potential Drought Damages by County

The estimation of potential drought damages is discussed in Section 4, including a brief overview of the methodology used to assess drought damages for each sector of the economy. This appendix provides a more in-depth discussion of these methodologies and provides the estimated potential drought damages by county.

## B1. Crop Damages

USDA Risk Management Agency (RMA) weekly Summary of Business data were obtained for Missouri from January 2000 to December 2020. Data in the Summary of Business database include state, county, year, month of loss, acres impacted, amount of indemnity paid and the cause of loss. Loss from drought is one of many causes of loss for which crop indemnity payments are made. Indemnity payments were filtered for drought-related losses and converted from nominal amounts to 2020 dollar amounts using the Midwest region monthly consumer price index from January 2000 to December 2020.

The USDM Drought Severity and Coverage Index (DSCI) value by year, month, and county was identified for each crop indemnity payment. Indemnity payments in the same month, year, and county have the same DSCI value. Additionally, there is not an indemnity payment for every month and year from January 2000 to December 2020.

Indemnity amounts were aggregated by year, month, and county. At least one indemnity payment from 2000 to 2020 occurred in each of 106 counties in the state.

The crop indemnity payments owing to drought from 2000 to 2020 are shown in **Tables B1** through **B4**, organized by county and level of drought severity using the USDM categories. The annualized number of payments are the total payments from 2000 to 2020 for the given county and drought category divided by the number of years in this period (21). The annualized payments and annualized number of acres by county are calculated in the same manner.

Table B1. Annualized Number of Payments by County, 2000 to 2020
Table B2. Annualized Payments by County, 2000 to 2020 (2020 Dollars)
Table B3. Annualized Number of Acres by County, 2000 to 2020
Table B4. Average Payment per Acre by County, 2000 to 2020 (2020 Dollars)

## B2. Livestock Damages

The inventory of cattle by county from 2000 to 2021 was obtained from the USDA National Agricultural Statistics Service (NASS) Missouri Field Office (USDA NASS 2021a). The inventory reported is based on January 1st of each year. On January 1, 2013, the cattle inventory was 250,000 head less than on January 1, 2012. This drop in inventory is indicative of the sell-off that occurred during the drought of 2012.

The decrease in cattle inventory from January 1, 2012, to January 1, 2013, is not uniform statewide but varied by county. This change in inventory is indicative of the impact of the drought of 2012. The change in inventory by county is shown in **Table B5**. Sixty-one percent of counties had a decrease in cattle inventory (highlighted in **Table B5**) while the remaining 39 percent of counties had an increase in cattle inventory during 2012. The net worth of the change in cattle inventory is estimated by assuming 500 pounds per head at $143.48 per hundredweight (cwt).

Table B5. 2021 Change in Cattle Inventory by County

The USDA Farm Service Agency (FSA) provides farmers with relief from drought damages to improved pasture and grazed forage crops through the Livestock Forage Program (LFP). The livestock owner is eligible for assistance if the land is in a county that has:

- D2 drought conditions for at least eight weeks (eligible for amount equal to one monthly payment)
- D3 conditions at any time (eligible for amount equal to three monthly payments)
- D3 conditions for at least four weeks, or D4 at any time (eligible for amount equal to four monthly payments)
- D4 conditions for at least four weeks (eligible for amount equal to five monthly payments)

The monthly rate is determined as a percentage of the monthly feed cost by livestock type.

Annual LFP payments by county by year from 2011 through 2020 were obtained in May 2021 from the USDA FSA Missouri State Office. **Table B6** shows the total LFP payments in millions of 2020 dollars by year and county.

Table B6. Total LFP Payments by County by Year in Million Dollars (2020 Dollars)

Section 4.2.3 uses the relative number of crop acres and livestock inventory to estimate the potential for agricultural impacts from drought by county relative to other counties within the state. Each county is assigned a value of 1 to 4 corresponding with the statewide quartiles of acres and quartiles of livestock and poultry inventories. A value of 1 suggests a relatively low potential for drought impacts and a value of 4 suggests a relatively high potential for drought impacts. Averaging the county scores for non-irrigated crop acres, and livestock and poultry inventories provides an overall agricultural potential relative impact score for the county. In Section 4.2.3, the comparison of potential for drought impact is summarized by region (crop reporting district). **Table B7** provides the potential for drought impact scores by county and **Table B8** ranks the counties by their overall scores.

Table B7. Relative Potential for Agricultural Drought Impact by County
Table B8. Counties Ranked by Relative Potential for Agricultural Drought Impact

## B3. Municipal Water Supply Damages

Section 4.3.2 uses data from the Missouri Water Resources Plan (MoDNR 2020) to estimate the potential for impacts from drought on municipal water supply by county relative to other counties within the state based on the population served and municipal water demand. Each county is assigned a value of 1 to 4 corresponding with the statewide quartiles of the projected 2020 population served by municipal water systems and the estimated 2020 county total, in millions of gallons per day (MGD), required by municipal systems. A value of 1 suggests a relatively low potential for drought impacts and a value of 4 suggests a relatively high potential for drought impacts. Averaging the county scores for population served and municipal water demand provides an overall municipal potential relative impact score for the county. In Section 4.3.2, the comparison of potential

for drought impact is summarized by region (crop reporting district). **Table B9** provides the potential for municipal drought impact scores by county and **Table B10** ranks the counties by their average scores.

Table B9. Relative Potential for Drought Impact on Municipal Water Supply by County
Table B10. Counties Ranked by Relative Potential for Drought Impact on Municipal Water Supply

## B4. Industrial Sector Damages

U.S. Geological Survey data for industrial and mining water use by county in MGD is used to estimate the potential for industrial impacts from drought in each county relative to other counties. Values of 1 to 4 are assigned to each county based on the rankings of water use. However, not all counties have reported industrial and/or mining water use.

Forty-seven counties have industrial water use, which is less than half of the counties. Counties without industrial water use are assigned a score of 1, counties with industrial water use up to 0.5 MGD are assigned a score of 2, counties with water use from 0.5 to 1.0 MGD are assigned a score of 3, and counties with industrial water use greater than 1.0 MGD are assigned a score of 4.

More counties have mining water use than industrial water use even though many have very low water use. Those counties without mining water use are assigned a score of 1, counties with mining water use up to 0.04 MGD are assigned a value of 2, counties with water use from 0.04 up to 0.1 MGD are assigned a value of 3, and counties with mining water use greater than 0.1 MGD are assigned a value of 4.

Each county has an overall score which is the average of the industrial and mining scores.

Table B11. Relative Potential for Industrial Drought Impact by County
Table B12. Counties Ranked by Relative Potential for Industrial Drought Impact

## B5. Tourism Sector Damages

The relative potential for drought impacts to tourism by county is estimated from the Missouri Division of Tourism annual reports (Missouri Division of Tourism 2021) and data obtained from the MoDNR Division of State Parks. The Division of Tourism data provides annual totals of tourism-related spending, employment, and state sales tax by county from 2011 to 2020. A 10-year average of tourism expenditures, employment and state sales tax is estimated for each county and used to assign a value of 1 to 4 by quartile. The Division of State Parks data on visitors and expenditures at state parks also covered the period of 2011 to 2020, although not all counties contain a state park. The 10-year average of state park visitors and expenditures is used to assign a value of 1 to 4 by quartile with a value of 1 assigned to counties without state parks. The scores for each of the categories is averaged by county to provide and overall relative impact score.

Table B13. Relative Potential for Drought Impact to Tourism by County
Table B14. Counties Ranked by Relative Potential for Drought Impact to Tourism

## B6. Relative Potential Damages

The overall scores of the relative potential for drought impacts for agriculture, municipal water supply, industry, and tourism are averaged for each county. The counties are then ranked by the overall average score for the relative potential for drought impacts. Note that the scores presented in Tables B15 and B16 are unweighted. Thus, each sector score carries the same weight.

Table B15. Overall Relative Potential for Drought Impact by County
Table B16. Counties Ranked by Overall Relative Potential for Drought Impact

**Table B1. Annualized Number of Payments by County, 2000 to 2020**

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Adair | 1.2 | 3.0 | 2.4 | 1.6 | 1.3 | 0.3 | 9.7 |
| Andrew | 2.4 | 2.4 | 3.9 | 2.2 | 2.5 | 0.1 | 13.4 |
| Atchison | 1.8 | 2.6 | 3.5 | 3.1 | 1.7 | 0.2 | 12.9 |
| Audrain | 5.4 | 3.3 | 6.1 | 2.2 | 1.5 | 0.5 | 18.9 |
| Barry | 0.8 | 2.2 | 1.8 | 0.4 | 0.6 | 0.2 | 5.9 |
| Barton | 7.7 | 5.5 | 5.4 | 4.6 | 1.2 | 0.4 | 24.6 |
| Bates | 6.5 | 7.4 | 3.9 | 5.0 | 0.2 | 0.5 | 23.3 |
| Benton | 2.5 | 2.4 | 3.8 | 1.9 | 1.0 | 0.4 | 12.0 |
| Bollinger | 2.2 | 1.9 | 0.9 | 0.5 | 0.5 | 0.5 | 6.4 |
| Boone | 2.3 | 2.8 | 2.4 | 2.5 | 1.3 | 0.3 | 11.6 |
| Buchanan | 2.0 | 3.3 | 4.4 | 2.3 | 2.0 | 0.5 | 14.3 |
| Butler | 2.4 | 2.2 | 1.0 | 1.2 | 0.4 | 0.3 | 7.4 |
| Caldwell | 4.1 | 2.3 | 4.5 | 3.1 | 2.7 | 0.6 | 17.2 |
| Callaway | 4.5 | 3.0 | 4.0 | 2.7 | 1.1 | 0.5 | 15.7 |
| Camden | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.3 |
| Cape Girardeau | 2.4 | 2.0 | 1.9 | 0.5 | 0.5 | 0.7 | 8.0 |
| Carroll | 3.7 | 3.3 | 6.8 | 2.0 | 3.0 | 0.6 | 19.3 |
| Cass | 3.2 | 5.6 | 3.4 | 1.8 | 1.5 | 0.3 | 15.8 |
| Cedar | 3.5 | 1.8 | 2.6 | 1.1 | 0.5 | 0.2 | 9.6 |
| Chariton | 3.2 | 3.3 | 4.5 | 1.8 | 2.4 | 0.4 | 15.5 |
| Christian | 0.3 | 0.7 | 0.7 | 0.2 | 0.1 | 0.0 | 1.9 |
| Clark | 4.1 | 5.2 | 3.1 | 4.7 | 2.3 | 0.4 | 19.6 |
| Clay | 0.8 | 1.6 | 2.7 | 1.0 | 1.4 | 0.2 | 7.6 |
| Clinton | 2.3 | 1.9 | 3.8 | 1.6 | 2.7 | 0.5 | 12.6 |
| Cole | 1.3 | 1.6 | 2.2 | 1.2 | 0.6 | 0.4 | 7.1 |
| Cooper | 3.1 | 4.4 | 3.5 | 2.4 | 1.6 | 0.6 | 15.4 |
| Crawford | 0.1 | 0.2 | 0.0 | 0.1 | 0.1 | 0.0 | 0.5 |
| Dade | 3.3 | 2.5 | 3.0 | 3.2 | 0.7 | 0.2 | 12.8 |
| Dallas | 0.3 | 1.1 | 0.6 | 0.0 | 0.2 | 0.0 | 2.1 |
| Daviess | 4.0 | 3.1 | 3.9 | 4.5 | 3.5 | 0.9 | 19.8 |
| DeKalb | 3.5 | 3.4 | 4.2 | 2.4 | 2.9 | 1.0 | 17.3 |
| Dent | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| Douglas | 0.1 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.4 |
| Dunklin | 4.2 | 6.4 | 3.8 | 3.1 | 0.6 | 1.2 | 19.2 |
| Franklin | 3.6 | 2.8 | 2.5 | 1.1 | 0.7 | 0.3 | 11.0 |
| Gasconade | 2.1 | 1.7 | 2.0 | 0.7 | 0.8 | 0.4 | 7.6 |
| Gentry | 4.0 | 2.9 | 3.6 | 3.9 | 2.6 | 0.5 | 17.3 |
| Greene | 1.1 | 1.8 | 2.2 | 0.1 | 0.6 | 0.2 | 5.9 |
| Grundy | 3.3 | 2.5 | 4.7 | 2.6 | 3.4 | 0.4 | 16.7 |
| Harrison | 3.9 | 3.2 | 3.9 | 3.1 | 3.4 | 0.0 | 17.4 |
| Henry | 5.5 | 4.7 | 5.7 | 2.5 | 2.0 | 0.7 | 21.0 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Hickory | 1.6 | 1.1 | 1.9 | 0.9 | 0.4 | 0.1 | 5.9 |
| Holt | 2.6 | 2.7 | 2.2 | 3.4 | 1.9 | 0.1 | 12.8 |
| Howard | 2.2 | 3.3 | 2.1 | 1.6 | 1.4 | 0.6 | 11.1 |
| Howell | 0.2 | 0.4 | 0.0 | 0.1 | 0.1 | 0.0 | 0.7 |
| Jackson | 1.0 | 3.6 | 2.2 | 0.6 | 1.4 | 0.3 | 9.0 |
| Jasper | 5.9 | 6.5 | 3.7 | 3.1 | 0.6 | 1.2 | 20.8 |
| Jefferson | 0.3 | 0.9 | 0.8 | 0.7 | 0.2 | 0.2 | 2.8 |
| Johnson | 3.5 | 5.9 | 5.0 | 2.2 | 2.1 | 0.5 | 19.0 |
| Knox | 2.9 | 5.3 | 3.9 | 3.4 | 0.9 | 0.4 | 16.7 |
| Laclede | 1.1 | 1.9 | 1.5 | 0.4 | 0.3 | 0.1 | 5.3 |
| Lafayette | 3.1 | 3.7 | 3.8 | 2.7 | 1.8 | 0.2 | 15.2 |
| Lawrence | 3.3 | 4.3 | 3.0 | 2.6 | 0.4 | 0.3 | 13.7 |
| Lewis | 4.3 | 4.2 | 2.9 | 3.0 | 1.4 | 0.3 | 16.0 |
| Lincoln | 5.4 | 5.9 | 5.8 | 3.0 | 1.2 | 0.6 | 21.7 |
| Linn | 2.7 | 4.1 | 4.0 | 2.8 | 2.9 | 0.3 | 16.7 |
| Livingston | 3.4 | 2.4 | 4.9 | 3.1 | 3.1 | 0.7 | 17.5 |
| Macon | 1.8 | 4.8 | 1.9 | 2.8 | 1.3 | 0.4 | 12.8 |
| Madison | 0.1 | 0.1 | 0.2 | 0.1 | 0.2 | 0.0 | 0.6 |
| Maries | 1.2 | 0.7 | 1.2 | 0.2 | 0.6 | 0.1 | 3.8 |
| Marion | 3.7 | 2.7 | 4.3 | 1.9 | 1.3 | 0.3 | 14.2 |
| McDonald | 0.1 | 0.3 | 0.5 | 0.3 | 0.0 | 0.0 | 1.0 |
| Mercer | 2.3 | 1.4 | 3.4 | 2.4 | 1.8 | 0.3 | 11.5 |
| Miller | 0.3 | 1.0 | 0.9 | 0.2 | 0.5 | 0.2 | 3.0 |
| Mississippi | 1.4 | 2.6 | 1.2 | 1.2 | 0.5 | 0.9 | 7.7 |
| Moniteau | 2.8 | 2.8 | 2.3 | 1.7 | 1.0 | 0.4 | 10.9 |
| Monroe | 5.4 | 5.0 | 5.6 | 1.8 | 1.8 | 0.4 | 19.9 |
| Montgomery | 4.5 | 2.9 | 4.2 | 2.0 | 1.3 | 0.4 | 15.2 |
| Morgan | 1.3 | 2.3 | 2.3 | 0.8 | 0.7 | 0.3 | 7.6 |
| New Madrid | 3.3 | 4.0 | 2.5 | 2.2 | 1.0 | 0.7 | 13.5 |
| Newton | 1.7 | 3.0 | 2.0 | 1.5 | 0.1 | 0.5 | 8.7 |
| Nodaway | 3.3 | 4.2 | 4.9 | 2.4 | 2.7 | 0.3 | 17.7 |
| Osage | 2.1 | 1.9 | 1.9 | 1.0 | 0.8 | 0.3 | 7.9 |
| Pemiscot | 5.1 | 4.9 | 3.4 | 2.6 | 2.3 | 0.8 | 18.9 |
| Perry | 1.7 | 3.0 | 1.2 | 1.5 | 0.5 | 0.3 | 8.0 |
| Pettis | 5.1 | 4.2 | 6.5 | 2.0 | 2.7 | 0.4 | 20.8 |
| Phelps | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 |
| Pike | 6.3 | 4.6 | 5.5 | 2.8 | 1.4 | 0.6 | 21.0 |
| Platte | 1.5 | 2.5 | 4.9 | 1.2 | 1.8 | 0.6 | 12.4 |
| Polk | 0.8 | 0.7 | 0.8 | 0.2 | 0.6 | 0.1 | 3.2 |
| Pulaski | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.0 | 0.6 |
| Putnam | 1.8 | 2.3 | 2.4 | 2.2 | 1.4 | 0.0 | 10.0 |
| Ralls | 6.2 | 3.3 | 4.1 | 2.0 | 1.5 | 0.6 | 17.4 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| **Randolph** | 2.0 | 3.3 | 2.4 | 1.4 | 1.2 | 0.2 | 10.3 |
| **Ray** | 2.3 | 4.3 | 4.5 | 2.8 | 2.2 | 0.5 | 16.5 |
| **Ripley** | 0.3 | 0.7 | 0.4 | 0.4 | 0.2 | 0.1 | 1.9 |
| **Saint Charles** | 4.5 | 5.3 | 4.6 | 1.7 | 0.9 | 0.6 | 17.5 |
| **Saint Clair** | 4.7 | 3.9 | 3.2 | 2.7 | 0.9 | 0.5 | 15.8 |
| **Saint Francois** | 0.3 | 0.4 | 0.1 | 0.2 | 0.2 | 0.1 | 1.2 |
| **Saint Louis** | 0.8 | 1.2 | 1.0 | 0.6 | 0.3 | 0.2 | 3.9 |
| **Ste Genevieve** | 1.8 | 3.3 | 0.9 | 1.6 | 0.5 | 0.3 | 8.2 |
| **Saline** | 3.6 | 4.3 | 5.4 | 2.0 | 1.7 | 0.5 | 17.4 |
| **Schuyler** | 1.7 | 3.2 | 2.8 | 2.4 | 1.0 | 0.2 | 11.2 |
| **Scotland** | 3.5 | 3.8 | 3.7 | 3.1 | 1.5 | 0.2 | 15.7 |
| **Scott** | 2.3 | 3.1 | 1.5 | 0.6 | 0.4 | 0.7 | 8.4 |
| **Shelby** | 3.5 | 4.9 | 3.6 | 2.6 | 1.6 | 0.4 | 16.4 |
| **Stoddard** | 4.0 | 4.8 | 2.8 | 1.9 | 0.8 | 1.0 | 15.2 |
| **Sullivan** | 1.7 | 3.2 | 3.7 | 2.0 | 2.4 | 0.6 | 13.5 |
| **Texas** | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| **Vernon** | 7.3 | 7.8 | 6.2 | 4.1 | 1.5 | 0.4 | 27.2 |
| **Warren** | 4.0 | 2.7 | 3.9 | 2.3 | 0.8 | 0.3 | 13.8 |
| **Washington** | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| **Wayne** | 0.5 | 0.4 | 0.4 | 0.0 | 0.2 | 0.1 | 1.5 |
| **Webster** | 0.9 | 1.3 | 1.4 | 0.0 | 0.4 | 0.2 | 4.1 |
| **Worth** | 2.3 | 2.2 | 2.5 | 1.2 | 1.3 | 0.0 | 9.4 |
| **Wright** | 0.3 | 1.1 | 0.4 | 0.1 | 0.1 | 0.0 | 1.8 |
| **State Total** | **270.0** | **296.9** | **292.5** | **180.8** | **122.2** | **34.9** | **1,197.1** |

Totals may not add up because of rounding.

*Source: USDA RMA*

**Table B2. Annualized Payments by County, 2000 to 2020 (2020 Dollars)**

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Adair | $27,238 | $71,373 | $91,680 | $103,618 | $445,207 | $37,238 | $776,352 |
| Andrew | $55,872 | $79,388 | $311,006 | $557,244 | $605,952 | $2 | $1,609,464 |
| Atchison | $49,087 | $162,886 | $447,815 | $918,583 | $343,040 | $2,108 | $1,923,519 |
| Audrain | $399,875 | $360,910 | $1,093,359 | $284,590 | $2,201,676 | $273,284 | $4,613,695 |
| Barry | $21,684 | $197,736 | $382,641 | $32,980 | $60,847 | $18,601 | $714,490 |
| Barton | $405,839 | $1,105,929 | $294,808 | $830,535 | $65,549 | $128,925 | $2,831,585 |
| Bates | $192,995 | $1,216,525 | $431,675 | $1,201,062 | $3,105 | $188,500 | $3,233,862 |
| Benton | $29,741 | $70,238 | $136,120 | $45,605 | $200,102 | $77,173 | $558,979 |
| Bollinger | $24,672 | $20,055 | $20,562 | $3,827 | $43,228 | $25,523 | $137,866 |
| Boone | $53,147 | $123,789 | $129,220 | $89,459 | $334,005 | $61,328 | $790,947 |
| Buchanan | $35,239 | $45,724 | $222,838 | $103,875 | $210,348 | $44,588 | $662,611 |
| Butler | $16,314 | $14,948 | $5,843 | $9,699 | $1,001 | $2,966 | $50,770 |
| Caldwell | $57,835 | $42,571 | $378,590 | $284,026 | $742,216 | $118,542 | $1,623,780 |
| Callaway | $181,213 | $88,657 | $307,335 | $129,154 | $536,803 | $59,391 | $1,302,552 |
| Camden | $0 | $828 | $1,806 | $0 | $0 | $0 | $2,634 |
| Cape Girardeau | $58,472 | $62,237 | $79,093 | $24,083 | $153,870 | $163,782 | $541,538 |
| Carroll | $49,910 | $258,168 | $430,105 | $66,160 | $820,019 | $184,595 | $1,808,958 |
| Cass | $61,047 | $312,840 | $414,966 | $62,369 | $339,781 | $113,998 | $1,305,001 |
| Cedar | $55,389 | $51,870 | $65,408 | $36,945 | $772 | $10,685 | $221,068 |
| Chariton | $100,904 | $169,931 | $445,408 | $41,945 | $808,552 | $161,146 | $1,727,886 |
| Christian | $7,050 | $33,746 | $16,489 | $2,992 | $2,123 | $0 | $62,400 |
| Clark | $145,631 | $204,321 | $161,244 | $310,867 | $609,400 | $198,001 | $1,629,464 |
| Clay | $13,787 | $24,751 | $156,410 | $14,908 | $221,832 | $19,505 | $451,194 |
| Clinton | $63,889 | $56,732 | $551,527 | $212,292 | $1,205,661 | $141,500 | $2,231,600 |
| Cole | $4,404 | $5,474 | $12,486 | $7,108 | $43,108 | $13,856 | $86,436 |
| Cooper | $74,695 | $427,612 | $372,659 | $122,357 | $1,143,511 | $276,832 | $2,417,666 |
| Crawford | $214 | $680 | $0 | $1,038 | $12,223 | $0 | $14,155 |
| Dade | $156,456 | $154,434 | $71,552 | $133,221 | $10,324 | $1,033 | $527,020 |
| Dallas | $3,962 | $31,791 | $18,641 | $0 | $5,903 | $0 | $60,296 |
| Daviess | $93,924 | $81,669 | $491,875 | $541,421 | $992,218 | $293,255 | $2,494,360 |
| DeKalb | $134,126 | $92,879 | $497,350 | $234,463 | $898,641 | $250,298 | $2,107,756 |
| Dent | $87 | $47 | $0 | $0 | $0 | $0 | $134 |
| Douglas | $712 | $2,695 | $1,438 | $0 | $0 | $0 | $4,845 |
| Dunklin | $29,639 | $90,895 | $46,767 | $29,264 | $8,509 | $15,560 | $220,636 |
| Franklin | $44,589 | $36,599 | $44,198 | $7,763 | $136,467 | $32,503 | $302,120 |
| Gasconade | $13,026 | $20,860 | $30,452 | $8,599 | $40,946 | $7,847 | $121,730 |
| Gentry | $153,162 | $130,997 | $500,874 | $776,670 | $457,492 | $103,942 | $2,123,137 |
| Greene | $13,486 | $78,219 | $57,789 | $388 | $38,824 | $9,580 | $198,286 |
| Grundy | $217,733 | $56,362 | $505,168 | $179,797 | $677,436 | $30,804 | $1,667,301 |
| Harrison | $235,909 | $424,345 | $608,547 | $1,103,294 | $750,866 | $0 | $3,122,961 |
| Henry | $99,641 | $235,207 | $332,244 | $72,087 | $411,892 | $206,431 | $1,357,502 |
| Hickory | $37,379 | $26,633 | $44,234 | $3,701 | $13,906 | $8,574 | $134,429 |
| Holt | $100,547 | $65,004 | $94,062 | $655,188 | $144,667 | $614 | $1,060,082 |
| Howard | $17,782 | $67,857 | $64,318 | $24,502 | $203,889 | $64,422 | $442,770 |
| Howell | $976 | $7,271 | $0 | $2,276 | $181 | $0 | $10,704 |
| Jackson | $20,340 | $124,429 | $103,772 | $23,276 | $185,678 | $35,394 | $492,889 |
| Jasper | $387,309 | $560,457 | $124,700 | $347,824 | $22,479 | $120,331 | $1,563,101 |
| Jefferson | $2,888 | $5,702 | $6,102 | $3,774 | $18,672 | $3,130 | $40,268 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Johnson | $54,867 | $269,677 | $379,347 | $93,157 | $651,524 | $275,681 | $1,724,252 |
| Knox | $132,315 | $475,521 | $824,274 | $564,369 | $1,409,109 | $400,511 | $3,806,099 |
| Laclede | $14,615 | $58,739 | $42,372 | $7,033 | $54,066 | $5,119 | $181,945 |
| Lafayette | $37,664 | $137,862 | $318,114 | $102,018 | $1,003,829 | $228,515 | $1,828,002 |
| Lawrence | $93,496 | $674,464 | $66,606 | $114,436 | $2,077 | $9,765 | $960,843 |
| Lewis | $358,585 | $567,561 | $799,620 | $554,512 | $1,253,811 | $481,889 | $4,015,977 |
| Lincoln | $164,964 | $79,214 | $246,214 | $91,282 | $439,924 | $135,973 | $1,157,571 |
| Linn | $128,865 | $377,972 | $165,627 | $426,049 | $740,837 | $160,837 | $2,000,188 |
| Livingston | $136,494 | $186,972 | $280,049 | $234,012 | $724,997 | $255,065 | $1,817,589 |
| Macon | $81,813 | $261,571 | $437,644 | $296,446 | $999,264 | $192,032 | $2,268,769 |
| Madison | $210 | $61 | $777 | $4,582 | $1,793 | $0 | $7,423 |
| Maries | $6,680 | $4,113 | $4,135 | $245 | $21,657 | $815 | $37,645 |
| Marion | $87,451 | $129,464 | $429,855 | $339,645 | $550,856 | $312,974 | $1,850,245 |
| McDonald | $789 | $20,246 | $51,839 | $29,913 | $0 | $0 | $102,787 |
| Mercer | $98,847 | $171,427 | $143,129 | $554,974 | $91,962 | $24,098 | $1,084,437 |
| Miller | $425 | $14,080 | $7,805 | $1,335 | $14,717 | $7,623 | $45,985 |
| Mississippi | $16,766 | $54,723 | $9,801 | $25,541 | $30,054 | $40,644 | $177,528 |
| Moniteau | $36,279 | $79,108 | $159,946 | $119,373 | $268,352 | $53,367 | $716,425 |
| Monroe | $309,745 | $295,253 | $593,150 | $346,449 | $1,553,243 | $180,143 | $3,277,984 |
| Montgomery | $158,679 | $172,016 | $306,667 | $111,337 | $774,309 | $88,130 | $1,611,138 |
| Morgan | $7,790 | $95,752 | $61,270 | $24,234 | $192,301 | $16,706 | $398,052 |
| New Madrid | $29,467 | $28,722 | $16,700 | $23,505 | $10,509 | $22,276 | $131,179 |
| Newton | $30,345 | $397,385 | $71,496 | $102,805 | $2,396 | $41,045 | $645,471 |
| Nodaway | $143,362 | $314,496 | $441,829 | $1,005,001 | $713,881 | $450 | $2,619,018 |
| Osage | $10,095 | $7,072 | $24,404 | $7,219 | $31,095 | $4,914 | $84,800 |
| Pemiscot | $120,285 | $177,244 | $69,384 | $33,089 | $74,070 | $28,816 | $502,888 |
| Perry | $29,005 | $87,123 | $13,071 | $202,971 | $158,914 | $34,913 | $525,998 |
| Pettis | $89,434 | $341,498 | $623,319 | $101,181 | $1,114,625 | $402,426 | $2,672,483 |
| Phelps | $103 | $85 | $0 | $156 | $0 | $0 | $344 |
| Pike | $285,757 | $289,802 | $455,831 | $244,194 | $1,144,293 | $250,389 | $2,670,265 |
| Platte | $31,363 | $24,622 | $237,661 | $24,488 | $284,609 | $31,761 | $634,505 |
| Polk | $12,264 | $20,273 | $38,214 | $899 | $26,225 | $549 | $98,424 |
| Pulaski | $499 | $829 | $1,125 | $1,138 | $5,429 | $0 | $9,019 |
| Putnam | $64,978 | $157,043 | $127,905 | $72,453 | $532,048 | $0 | $954,427 |
| Ralls | $390,628 | $75,139 | $451,815 | $283,533 | $987,219 | $343,633 | $2,531,967 |
| Randolph | $121,251 | $85,109 | $247,630 | $21,172 | $365,167 | $90,762 | $931,091 |
| Ray | $29,027 | $150,510 | $192,680 | $71,694 | $473,610 | $79,000 | $996,522 |
| Ripley | $494 | $2,633 | $1,043 | $549 | $2,563 | $1,638 | $8,920 |
| Saint Charles | $50,536 | $92,463 | $108,487 | $17,106 | $187,078 | $104,620 | $560,288 |
| Saint Clair | $71,874 | $245,598 | $119,589 | $278,120 | $8,152 | $60,868 | $784,201 |
| Saint Francois | $1,242 | $3,097 | $433 | $6,056 | $15,879 | $194 | $26,901 |
| Saint Louis | $3,501 | $6,154 | $21,252 | $3,268 | $6,542 | $7,793 | $48,511 |
| Ste Genevieve | $21,364 | $38,915 | $4,142 | $62,565 | $56,290 | $23,041 | $206,318 |
| Saline | $60,117 | $173,162 | $215,835 | $48,867 | $1,401,051 | $263,805 | $2,162,836 |
| Schuyler | $68,930 | $137,487 | $107,207 | $77,401 | $346,562 | $2,852 | $740,440 |
| Scotland | $200,461 | $289,085 | $336,991 | $151,516 | $821,322 | $81,542 | $1,880,916 |
| Scott | $24,995 | $14,714 | $18,618 | $3,949 | $34,241 | $83,351 | $179,867 |
| Shelby | $120,488 | $426,336 | $542,784 | $305,767 | $1,223,129 | $159,950 | $2,778,454 |
| Stoddard | $65,730 | $115,716 | $59,607 | $21,904 | $45,396 | $71,209 | $379,562 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| **Sullivan** | $35,856 | $182,839 | $71,559 | $235,319 | $463,625 | $88,514 | $1,077,712 |
| **Texas** | $1,854 | $2,775 | $0 | $0 | $0 | $0 | $4,628 |
| **Vernon** | $380,028 | $1,006,345 | $489,970 | $1,095,997 | $17,504 | $140,003 | $3,129,847 |
| **Warren** | $64,446 | $31,964 | $82,841 | $33,149 | $233,343 | $25,643 | $471,385 |
| **Washington** | $0 | $235 | $0 | $0 | $0 | $0 | $235 |
| **Wayne** | $4,169 | $3,143 | $2,746 | $0 | $4,325 | $2,861 | $17,244 |
| **Webster** | $11,271 | $94,147 | $70,999 | $0 | $26,101 | $3,048 | $205,567 |
| **Worth** | $53,438 | $109,254 | $140,964 | $214,671 | $71,679 | $0 | $590,008 |
| **Wright** | $24,536 | $59,916 | $5,418 | $573 | $4,218 | $0 | $94,661 |
| **State Total** | **$8,530,344** | **$16,823,001** | **$21,346,967** | **$18,438,046** | **$37,844,690** | **$8,827,536** | **$111,810,585** |

Totals may not add up Because of rounding.

*Source: USDA RMA*

**Table B3. Annualized Number of Acres by County, 2000 to 2020**

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| Adair | 226.7 | 942.3 | 838.4 | 689.3 | 1,861.0 | 167.9 | 4,725.6 |
| Andrew | 570.3 | 749.9 | 2,581.1 | 2,745.1 | 4,495.7 | 7.3 | 11,149.4 |
| Atchison | 409.7 | 1,528.1 | 4,743.9 | 6,803.7 | 2,607.7 | 29.6 | 16,122.6 |
| Audrain | 4,519.9 | 4,377.7 | 7,824.5 | 3,450.8 | 7,053.9 | 932.0 | 28,158.8 |
| Barry | 140.6 | 887.9 | 697.0 | 195.9 | 185.4 | 57.2 | 2,163.9 |
| Barton | 3,255.5 | 4,973.5 | 3,235.8 | 4,387.3 | 668.0 | 540.9 | 17,061.1 |
| Bates | 2,542.8 | 8,404.6 | 3,259.9 | 5,719.0 | 67.9 | 947.8 | 20,942.0 |
| Benton | 358.8 | 672.5 | 1,036.5 | 555.0 | 582.5 | 346.0 | 3,551.4 |
| Bollinger | 289.6 | 210.5 | 183.2 | 42.3 | 121.2 | 146.3 | 993.1 |
| Boone | 658.9 | 1,297.7 | 834.4 | 1,245.2 | 1,277.8 | 219.6 | 5,533.6 |
| Buchanan | 254.2 | 526.8 | 2,192.5 | 1,037.9 | 1,407.7 | 255.7 | 5,674.8 |
| Butler | 151.4 | 238.4 | 123.7 | 147.8 | 36.7 | 14.0 | 712.0 |
| Caldwell | 545.4 | 575.5 | 2,988.8 | 1,930.8 | 3,602.0 | 548.9 | 10,191.4 |
| Callaway | 1,904.9 | 969.4 | 1,858.2 | 1,599.9 | 1,884.6 | 279.9 | 8,496.9 |
| Camden | 0.0 | 5.7 | 12.3 | 0.0 | 0.0 | 0.0 | 18.0 |
| Cape Girardeau | 297.8 | 615.6 | 649.4 | 123.7 | 533.4 | 716.1 | 2,935.8 |
| Carroll | 562.7 | 1,710.5 | 3,637.6 | 628.6 | 4,995.3 | 797.3 | 12,332.0 |
| Cass | 711.9 | 2,955.8 | 2,724.6 | 728.8 | 1,702.8 | 618.8 | 9,442.7 |
| Cedar | 368.8 | 260.3 | 543.1 | 207.6 | 14.8 | 99.1 | 1,493.7 |
| Chariton | 882.0 | 1,251.1 | 3,837.2 | 542.7 | 4,300.3 | 853.4 | 11,666.7 |
| Christian | 28.8 | 94.3 | 83.2 | 14.0 | 4.0 | 0.0 | 224.3 |
| Clark | 1,176.0 | 1,975.8 | 1,552.5 | 3,329.7 | 2,427.9 | 820.1 | 11,282.1 |
| Clay | 102.2 | 247.4 | 1,207.7 | 216.5 | 1,195.5 | 86.5 | 3,055.8 |
| Clinton | 529.3 | 908.2 | 3,597.9 | 1,491.1 | 5,705.4 | 348.2 | 12,580.2 |
| Cole | 69.8 | 80.5 | 134.1 | 100.2 | 196.8 | 74.6 | 656.0 |
| Cooper | 620.7 | 3,788.2 | 3,322.2 | 1,411.6 | 3,904.1 | 1,234.5 | 14,281.2 |
| Crawford | 2.5 | 17.2 | 0.0 | 3.6 | 24.9 | 0.0 | 48.3 |
| Dade | 762.2 | 1,004.2 | 838.6 | 1,337.8 | 208.0 | 7.9 | 4,158.8 |
| Dallas | 17.6 | 103.7 | 73.9 | 0.0 | 36.0 | 0.0 | 231.3 |
| Daviess | 785.1 | 903.0 | 3,332.9 | 4,237.2 | 5,628.9 | 1,282.9 | 16,170.0 |
| DeKalb | 1,097.2 | 1,135.7 | 3,445.7 | 2,069.3 | 5,007.0 | 1,128.4 | 13,883.3 |
| Dent | 0.9 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 |
| Douglas | 3.8 | 17.6 | 9.3 | 0.0 | 0.0 | 0.0 | 30.8 |
| Dunklin | 475.1 | 1,120.1 | 641.5 | 574.2 | 112.2 | 131.5 | 3,054.6 |
| Franklin | 418.4 | 337.2 | 351.8 | 76.7 | 497.0 | 135.3 | 1,816.3 |
| Gasconade | 145.6 | 146.1 | 211.2 | 84.5 | 151.7 | 53.2 | 792.3 |
| Gentry | 1,159.2 | 1,230.0 | 3,153.9 | 4,017.4 | 3,219.5 | 723.1 | 13,503.0 |
| Greene | 84.3 | 277.7 | 386.0 | 2.2 | 112.8 | 39.1 | 902.1 |
| Grundy | 1,033.7 | 592.7 | 4,437.9 | 1,386.8 | 4,131.2 | 297.0 | 11,879.2 |
| Harrison | 1,367.2 | 3,371.0 | 3,604.5 | 4,762.3 | 5,673.1 | 0.0 | 18,778.0 |
| Henry | 1,657.3 | 2,276.4 | 2,967.8 | 916.6 | 1,684.4 | 1,245.2 | 10,747.7 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| **Hickory** | 179.1 | 167.2 | 254.5 | 68.0 | 40.1 | 39.9 | 748.7 |
| **Holt** | 953.4 | 483.9 | 932.6 | 4,673.0 | 1,004.3 | 4.8 | 8,052.0 |
| **Howard** | 274.7 | 592.6 | 542.5 | 203.3 | 1,050.8 | 445.3 | 3,109.1 |
| **Howell** | 9.0 | 75.9 | 0.0 | 21.5 | 0.9 | 0.0 | 107.4 |
| **Jackson** | 253.1 | 1,553.9 | 1,057.4 | 239.2 | 941.2 | 225.6 | 4,270.5 |
| **Jasper** | 1,819.3 | 3,033.3 | 1,687.7 | 2,058.9 | 214.4 | 692.6 | 9,506.2 |
| **Jefferson** | 24.4 | 55.9 | 46.3 | 35.1 | 68.2 | 33.3 | 263.2 |
| **Johnson** | 714.7 | 2,948.3 | 3,637.5 | 1,042.1 | 2,813.2 | 1,298.5 | 12,454.2 |
| **Knox** | 1,108.0 | 3,925.6 | 6,117.1 | 3,668.4 | 3,795.6 | 1,063.3 | 19,677.9 |
| **Laclede** | 112.1 | 321.7 | 258.0 | 56.7 | 150.0 | 27.8 | 926.3 |
| **Lafayette** | 542.5 | 1,836.7 | 2,645.2 | 1,285.1 | 4,914.0 | 1,088.1 | 12,311.6 |
| **Lawrence** | 620.1 | 2,339.8 | 779.1 | 695.6 | 26.2 | 46.3 | 4,507.0 |
| **Lewis** | 2,859.6 | 3,514.1 | 5,530.3 | 3,834.4 | 3,296.8 | 1,617.0 | 20,652.2 |
| **Lincoln** | 1,587.8 | 1,047.0 | 1,871.2 | 1,132.4 | 1,368.8 | 554.6 | 7,561.9 |
| **Linn** | 1,008.0 | 2,534.3 | 1,835.6 | 2,488.8 | 4,178.1 | 787.8 | 12,832.5 |
| **Livingston** | 788.8 | 1,621.2 | 2,961.4 | 1,648.5 | 3,794.2 | 1,451.8 | 12,265.9 |
| **Macon** | 845.7 | 2,514.3 | 3,394.5 | 2,399.2 | 3,711.2 | 837.2 | 13,702.0 |
| **Madison** | 3.7 | 1.5 | 6.1 | 11.9 | 9.3 | 0.0 | 32.4 |
| **Maries** | 74.0 | 39.7 | 34.4 | 3.6 | 102.6 | 23.6 | 277.9 |
| **Marion** | 1,182.3 | 1,358.4 | 4,043.7 | 2,497.4 | 1,654.2 | 1,408.3 | 12,144.3 |
| **McDonald** | 1.6 | 62.3 | 110.0 | 96.5 | 0.0 | 0.0 | 270.4 |
| **Mercer** | 568.6 | 1,134.1 | 990.2 | 2,349.4 | 676.6 | 59.8 | 5,778.7 |
| **Miller** | 4.2 | 107.5 | 74.3 | 29.5 | 72.6 | 29.7 | 317.8 |
| **Mississippi** | 154.8 | 413.9 | 94.9 | 366.3 | 166.6 | 186.3 | 1,382.9 |
| **Moniteau** | 479.3 | 859.6 | 784.3 | 1,354.5 | 977.5 | 239.3 | 4,694.5 |
| **Monroe** | 3,014.1 | 3,448.1 | 3,978.4 | 3,064.1 | 4,730.6 | 499.9 | 18,735.3 |
| **Montgomery** | 1,766.7 | 1,964.4 | 2,343.3 | 1,700.0 | 2,578.4 | 369.9 | 10,722.6 |
| **Morgan** | 95.6 | 841.5 | 535.6 | 219.3 | 582.1 | 69.1 | 2,343.1 |
| **New Madrid** | 331.7 | 531.2 | 313.9 | 394.3 | 117.9 | 147.9 | 1,837.0 |
| **Newton** | 189.3 | 1,123.2 | 394.5 | 470.9 | 5.6 | 193.2 | 2,376.8 |
| **Nodaway** | 1,079.9 | 2,946.0 | 4,329.9 | 4,842.0 | 6,137.4 | 12.1 | 19,347.3 |
| **Osage** | 95.4 | 64.4 | 137.0 | 78.7 | 153.0 | 35.2 | 563.7 |
| **Pemiscot** | 1,122.6 | 2,370.0 | 1,165.1 | 444.3 | 1,086.3 | 216.6 | 6,404.9 |
| **Perry** | 298.9 | 620.0 | 141.5 | 788.4 | 790.7 | 145.9 | 2,785.4 |
| **Pettis** | 1,314.9 | 3,668.0 | 7,016.9 | 1,222.7 | 4,224.2 | 2,072.0 | 19,518.7 |
| **Phelps** | 0.2 | 0.4 | 0.0 | 2.5 | 0.0 | 0.0 | 3.1 |
| **Pike** | 3,148.7 | 2,780.6 | 3,272.5 | 2,806.3 | 3,261.2 | 851.6 | 16,120.9 |
| **Platte** | 122.9 | 451.8 | 2,169.3 | 231.3 | 1,812.1 | 145.5 | 4,933.0 |
| **Polk** | 56.6 | 97.7 | 199.0 | 8.6 | 126.1 | 0.9 | 488.9 |
| **Pulaski** | 4.4 | 7.7 | 8.7 | 8.9 | 16.9 | 0.0 | 46.6 |
| **Putnam** | 368.2 | 1,103.8 | 905.0 | 547.1 | 1,971.0 | 0.0 | 4,895.1 |
| **Ralls** | 3,244.2 | 847.4 | 2,236.5 | 2,397.7 | 3,267.4 | 801.2 | 12,794.5 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Total |
|---|---|---|---|---|---|---|---|
| **Randolph** | 909.5 | 1,037.0 | 1,547.8 | 218.9 | 1,296.6 | 416.7 | 5,426.5 |
| **Ray** | 286.7 | 1,155.9 | 1,753.5 | 675.2 | 2,848.0 | 349.9 | 7,069.2 |
| **Ripley** | 5.4 | 47.8 | 21.2 | 18.0 | 10.2 | 4.4 | 107.1 |
| **Saint Charles** | 502.7 | 1,146.2 | 978.9 | 207.9 | 744.3 | 460.4 | 4,040.4 |
| **Saint Clair** | 844.4 | 1,727.0 | 1,080.8 | 1,478.6 | 118.3 | 425.8 | 5,675.0 |
| **Saint Francois** | 7.3 | 25.8 | 4.1 | 14.2 | 62.0 | 5.1 | 118.4 |
| **Saint Louis** | 42.0 | 98.2 | 134.8 | 31.9 | 52.8 | 39.2 | 398.9 |
| **Ste Genevieve** | 144.7 | 429.0 | 59.8 | 254.5 | 225.3 | 87.9 | 1,201.1 |
| **Saline** | 642.4 | 1,778.3 | 2,386.0 | 606.1 | 4,967.5 | 1,372.8 | 11,753.0 |
| **Schuyler** | 429.3 | 1,262.5 | 911.8 | 467.8 | 1,285.8 | 17.0 | 4,374.2 |
| **Scotland** | 1,554.9 | 2,607.8 | 3,262.1 | 1,094.8 | 3,366.6 | 302.8 | 12,189.0 |
| **Scott** | 331.3 | 488.0 | 304.5 | 54.9 | 147.8 | 294.6 | 1,621.1 |
| **Shelby** | 1,304.1 | 3,713.4 | 4,419.9 | 2,358.0 | 4,136.2 | 567.8 | 16,499.3 |
| **Stoddard** | 528.8 | 1,032.4 | 616.4 | 299.5 | 238.4 | 377.1 | 3,092.5 |
| **Sullivan** | 264.2 | 1,506.7 | 828.1 | 1,460.1 | 2,460.3 | 397.7 | 6,917.1 |
| **Texas** | 10.6 | 15.9 | 0.0 | 0.0 | 0.0 | 0.0 | 26.5 |
| **Vernon** | 3,930.3 | 5,585.5 | 5,676.2 | 5,902.0 | 257.4 | 1,173.8 | 22,525.2 |
| **Warren** | 880.1 | 465.9 | 813.3 | 371.5 | 720.2 | 110.6 | 3,361.6 |
| **Washington** | 0.0 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 3.6 |
| **Wayne** | 46.0 | 43.2 | 18.9 | 0.0 | 12.1 | 16.4 | 136.6 |
| **Webster** | 44.2 | 266.6 | 306.7 | 0.0 | 69.4 | 14.5 | 701.5 |
| **Worth** | 372.5 | 755.2 | 1,063.2 | 1,153.3 | 570.5 | 0.0 | 3,914.7 |
| **Wright** | 88.7 | 160.5 | 20.4 | 2.4 | 6.6 | 0.0 | 278.6 |
| **State Total** | **75,782.0** | **133,542.4** | **172,199.4** | **126,968.7** | **166,803.4** | **39,341.4** | **714,637.3** |

Totals may not add up Because of rounding.

*Source: USDA RMA*

**Table B4. Average Payment per Acre by County, 2000 to 2020 (2020 Dollars)**

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Average* |
|---|---|---|---|---|---|---|---|
| Adair | $115.33 | $93.76 | $86.00 | $158.11 | $200.28 | $402.30 | $127.41 |
| Andrew | $88.99 | $77.51 | $115.43 | $157.52 | $117.25 | $0.34 | $110.45 |
| Atchison | $115.95 | $107.73 | $97.40 | $139.78 | $102.98 | $91.14 | $113.03 |
| Audrain | $106.85 | $82.75 | $109.25 | $71.88 | $219.50 | $263.76 | $112.23 |
| Barry | $152.08 | $175.61 | $199.88 | $207.52 | $359.56 | $273.83 | $204.09 |
| Barton | $128.51 | $120.63 | $82.02 | $138.81 | $65.96 | $261.81 | $117.56 |
| Bates | $97.88 | $117.14 | $91.64 | $110.80 | $107.50 | $182.70 | $107.49 |
| Benton | $113.22 | $109.72 | $114.07 | $87.25 | $213.08 | $287.55 | $122.39 |
| Bollinger | $112.30 | $84.79 | $137.86 | $112.66 | $273.06 | $185.36 | $125.08 |
| Boone | $102.17 | $83.10 | $121.54 | $76.47 | $228.34 | $310.67 | $115.86 |
| Buchanan | $192.72 | $172.49 | $140.28 | $117.01 | $116.79 | $135.29 | $147.80 |
| Butler | $98.66 | $73.52 | $60.80 | $64.79 | $72.37 | $165.14 | $81.63 |
| Caldwell | $101.45 | $74.46 | $100.76 | $114.71 | $160.19 | $225.09 | $113.65 |
| Callaway | $92.64 | $115.73 | $112.06 | $98.59 | $214.54 | $256.70 | $116.08 |
| Camden | $0.00 | $147.31 | $140.98 | $0.00 | $0.00 | $0.00 | $143.52 |
| Cape Girardeau | $150.42 | $82.51 | $150.74 | $176.71 | $301.86 | $255.35 | $153.37 |
| Carroll | $97.24 | $128.50 | $92.97 | $90.32 | $145.11 | $256.89 | $112.89 |
| Cass | $113.86 | $105.88 | $101.04 | $114.29 | $150.74 | $271.97 | $114.91 |
| Cedar | $114.15 | $148.98 | $112.67 | $148.52 | $54.10 | $192.19 | $121.94 |
| Chariton | $114.99 | $86.84 | $111.40 | $96.42 | $147.24 | $242.35 | $114.23 |
| Christian | $178.28 | $267.00 | $231.21 | $138.51 | $531.94 | $0.00 | $245.37 |
| Clark | $114.58 | $92.99 | $112.40 | $100.04 | $127.85 | $320.34 | $110.92 |
| Clay | $146.71 | $99.80 | $110.09 | $86.91 | $169.83 | $236.50 | $121.75 |
| Clinton | $90.78 | $70.81 | $115.07 | $112.75 | $136.52 | $321.91 | $116.60 |
| Cole | $90.76 | $84.29 | $108.96 | $69.69 | $304.40 | $211.18 | $112.69 |
| Cooper | $137.26 | $102.74 | $124.25 | $82.69 | $162.46 | $249.29 | $122.62 |
| Crawford | $86.13 | $87.49 | $0.00 | $287.04 | $492.02 | $0.00 | $221.58 |
| Dade | $137.81 | $132.93 | $79.18 | $109.74 | $62.49 | $156.96 | $112.81 |
| Dallas | $241.60 | $272.66 | $185.24 | $0.00 | $216.34 | $0.00 | $240.54 |
| Daviess | $100.22 | $96.84 | $105.52 | $120.17 | $128.68 | $270.82 | $118.03 |
| DeKalb | $122.75 | $83.16 | $122.41 | $110.44 | $133.41 | $205.22 | $119.42 |
| Dent | $94.80 | $185.53 | $0.00 | $0.00 | $0.00 | $0.00 | $140.17 |
| Douglas | $185.48 | $170.60 | $155.65 | $0.00 | $0.00 | $0.00 | $168.72 |
| Dunklin | $103.41 | $111.75 | $105.05 | $59.49 | $81.11 | $124.41 | $100.08 |
| Franklin | $112.92 | $99.36 | $82.38 | $85.12 | $201.89 | $295.08 | $110.73 |
| Gasconade | $108.44 | $142.51 | $121.46 | $122.25 | $196.57 | $215.06 | $134.57 |
| Gentry | $127.68 | $121.49 | $126.52 | $127.74 | $125.21 | $254.03 | $129.78 |
| Greene | $171.60 | $223.55 | $179.85 | $176.15 | $260.04 | $321.08 | $203.76 |
| Grundy | $133.26 | $97.03 | $101.56 | $116.90 | $163.91 | $164.87 | $123.40 |
| Harrison | $156.72 | $86.94 | $124.33 | $170.40 | $123.49 | $0.00 | $132.89 |
| Henry | $78.95 | $105.65 | $101.14 | $82.12 | $130.41 | $205.04 | $100.32 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Average* |
|---|---|---|---|---|---|---|---|
| Hickory | $138.99 | $148.82 | $123.29 | $81.38 | $256.14 | $220.51 | $136.13 |
| Holt | $122.08 | $127.66 | $108.79 | $114.81 | $114.37 | $82.21 | $117.69 |
| Howard | $98.09 | $96.70 | $112.48 | $118.02 | $152.72 | $198.46 | $115.14 |
| Howell | $137.89 | $99.38 | $0.00 | $99.71 | $196.93 | $0.00 | $117.40 |
| Jackson | $93.91 | $89.59 | $98.36 | $73.59 | $124.28 | $235.78 | $100.64 |
| Jasper | $137.23 | $117.02 | $77.74 | $137.67 | $134.08 | $108.62 | $118.85 |
| Jefferson | $79.86 | $99.26 | $97.71 | $146.11 | $331.72 | $149.17 | $123.95 |
| Johnson | $87.83 | $96.56 | $105.49 | $84.76 | $148.55 | $280.24 | $106.06 |
| Knox | $132.19 | $112.82 | $117.14 | $166.63 | $258.89 | $398.70 | $142.29 |
| Laclede | $117.35 | $200.63 | $175.06 | $118.20 | $396.06 | $137.08 | $179.95 |
| Lafayette | $129.61 | $80.43 | $100.11 | $105.14 | $202.58 | $200.08 | $115.90 |
| Lawrence | $139.43 | $179.67 | $84.82 | $144.53 | $80.44 | $234.77 | $141.06 |
| Lewis | $115.61 | $125.37 | $106.65 | $170.56 | $161.64 | $260.65 | $133.56 |
| Lincoln | $106.96 | $85.55 | $115.99 | $98.19 | $278.92 | $210.16 | $114.27 |
| Linn | $115.60 | $105.64 | $93.08 | $126.71 | $144.96 | $282.56 | $117.90 |
| Livingston | $130.24 | $82.48 | $95.65 | $119.35 | $144.47 | $266.50 | $120.19 |
| Macon | $102.08 | $109.15 | $105.04 | $164.22 | $236.45 | $372.18 | $140.41 |
| Madison | $65.76 | $40.41 | $132.43 | $507.84 | $212.89 | $0.00 | $203.04 |
| Maries | $109.93 | $133.79 | $109.72 | $62.10 | $260.29 | $34.52 | $135.48 |
| Marion | $84.14 | $91.19 | $110.86 | $137.99 | $134.43 | $300.99 | $109.95 |
| McDonald | $496.41 | $379.26 | $350.52 | $279.41 | $0.00 | $0.00 | $345.53 |
| Mercer | $159.29 | $148.41 | $127.22 | $177.97 | $149.72 | $396.37 | $156.01 |
| Miller | $95.68 | $127.93 | $122.02 | $24.13 | $235.46 | $264.41 | $142.73 |
| Mississippi | $172.25 | $145.94 | $119.64 | $161.91 | $173.88 | $220.08 | $159.17 |
| Moniteau | $97.41 | $100.67 | $132.06 | $72.29 | $235.63 | $249.94 | $119.20 |
| Monroe | $98.56 | $89.96 | $136.50 | $133.48 | $204.77 | $320.82 | $124.06 |
| Montgomery | $92.37 | $122.94 | $115.51 | $72.87 | $284.76 | $250.93 | $122.12 |
| Morgan | $92.54 | $108.97 | $124.54 | $103.86 | $273.49 | $239.65 | $130.18 |
| New Madrid | $95.41 | $78.25 | $85.37 | $95.47 | $119.18 | $220.76 | $96.02 |
| Newton | $131.14 | $178.55 | $154.03 | $210.57 | $361.00 | $181.10 | $171.29 |
| Nodaway | $113.46 | $96.57 | $92.02 | $135.79 | $128.72 | $43.37 | $107.78 |
| Osage | $96.88 | $111.90 | $130.57 | $67.24 | $225.97 | $142.36 | $119.12 |
| Pemiscot | $101.96 | $91.58 | $82.46 | $107.71 | $80.03 | $138.62 | $95.30 |
| Perry | $120.99 | $124.26 | $113.71 | $240.00 | $267.55 | $242.58 | $155.00 |
| Pettis | $64.66 | $96.65 | $100.69 | $91.10 | $128.95 | $312.74 | $97.95 |
| Phelps | $623.63 | $239.84 | $0.00 | $61.60 | $0.00 | $0.00 | $308.36 |
| Pike | $106.78 | $114.67 | $116.68 | $110.17 | $237.62 | $276.72 | $124.92 |
| Platte | $301.91 | $88.80 | $185.63 | $169.39 | $301.83 | $254.84 | $198.14 |
| Polk | $231.72 | $187.63 | $186.88 | $111.40 | $208.75 | $610.34 | $204.53 |
| Pulaski | $110.93 | $109.71 | $148.90 | $111.79 | $397.77 | $0.00 | $212.81 |
| Putnam | $181.59 | $147.39 | $115.00 | $176.84 | $272.28 | $0.00 | $169.32 |
| Ralls | $126.02 | $85.32 | $136.14 | $129.43 | $194.34 | $299.62 | $132.51 |

| County | Not Dry | D0 | D1 | D2 | D3 | D4 | Average* |
|---|---|---|---|---|---|---|---|
| Randolph | $116.96 | $80.88 | $137.19 | $113.25 | $227.72 | $258.27 | $124.25 |
| Ray | $85.70 | $101.73 | $121.91 | $92.52 | $163.95 | $269.04 | $116.31 |
| Ripley | $103.21 | $75.17 | $77.75 | $27.52 | $207.28 | $370.11 | $89.11 |
| Saint Charles | $117.80 | $87.63 | $112.42 | $97.00 | $294.64 | $202.59 | $117.36 |
| Saint Clair | $100.54 | $134.65 | $107.36 | $114.30 | $53.94 | $189.46 | $112.60 |
| Saint Francois | $176.86 | $108.35 | $133.52 | $450.58 | $288.50 | $38.08 | $198.35 |
| Saint Louis | $135.55 | $73.02 | $132.07 | $117.07 | $190.70 | $118.04 | $116.23 |
| Ste Genevieve | $149.36 | $93.09 | $79.80 | $136.78 | $255.06 | $319.67 | $128.26 |
| Saline | $72.24 | $90.63 | $78.44 | $86.86 | $164.36 | $304.35 | $95.33 |
| Schuyler | $134.95 | $102.94 | $108.40 | $142.27 | $268.99 | $226.56 | $134.74 |
| Scotland | $113.26 | $107.38 | $95.22 | $144.88 | $174.58 | $321.51 | $122.58 |
| Scott | $96.09 | $58.78 | $96.12 | $78.19 | $101.38 | $209.22 | $90.73 |
| Shelby | $88.09 | $79.06 | $101.13 | $159.81 | $164.20 | $286.12 | $110.91 |
| Stoddard | $148.41 | $118.48 | $143.75 | $93.31 | $150.64 | $206.41 | $135.09 |
| Sullivan | $125.83 | $133.69 | $91.37 | $190.07 | $175.46 | $259.23 | $141.75 |
| Texas | $174.89 | $174.55 | $0.00 | $0.00 | $0.00 | $0.00 | $174.72 |
| Vernon | $112.59 | $103.45 | $78.22 | $143.72 | $53.14 | $222.18 | $104.89 |
| Warren | $79.71 | $75.61 | $97.05 | $120.19 | $362.26 | $194.42 | $108.39 |
| Washington | $0.00 | $65.64 | $0.00 | $0.00 | $0.00 | $0.00 | $65.64 |
| Wayne | $111.82 | $99.13 | $183.04 | $0.00 | $246.46 | $186.84 | $149.69 |
| Webster | $230.33 | $252.60 | $163.07 | $0.00 | $311.43 | $264.51 | $222.87 |
| Worth | $148.96 | $121.23 | $129.01 | $226.57 | $152.38 | $0.00 | $147.93 |
| Wright | $291.90 | $228.79 | $310.15 | $236.66 | $640.02 | $0.00 | $266.77 |
| **State Total** | **$115.35** | **$109.47** | **$112.09** | **$122.62** | **$169.03** | **$232.29** | **$123.10** |

Totals may not add up Because of rounding.
*The average is weighted by the number of acres per category.
*Source: USDA RMA*

**Table B5. 2012 Change in Cattle Inventory by County**

| County | Jan 1, 2012 | Jan 1, 2013 | Change | % Change | Net Worth[1] |
|---|---|---|---|---|---|
| Adair | 34,000 | 37,500 | 3,500 | 10.3% | $2,510,900 |
| Andrew | 23,000 | 16,500 | -6,500 | -28.3% | -$4,663,100 |
| Atchison | 9,800 | 6,800 | -3,000 | -30.6% | -$2,152,200 |
| Audrain | 37,000 | 32,000 | -5,000 | -13.5% | -$3,587,000 |
| Barry | 79,000 | 76,000 | -3,000 | -3.8% | -$2,152,200 |
| Barton | 45,500 | 36,000 | -9,500 | -20.9% | -$6,815,300 |
| Bates | 72,000 | 63,000 | -9,000 | -12.5% | -$6,456,600 |
| Benton | 36,500 | 42,500 | 6,000 | 16.4% | $4,304,400 |
| Bollinger | 29,000 | 24,000 | -5,000 | -17.2% | -$3,587,000 |
| Boone | 29,000 | 19,100 | -9,900 | -34.1% | -$7,102,260 |
| Buchanan | 16,300 | 14,700 | -1,600 | -9.8% | -$1,147,840 |
| Butler | 4,800 | 6,500 | 1,700 | 35.4% | $1,219,580 |
| Caldwell | 29,500 | 21,000 | -8,500 | -28.8% | -$6,097,900 |
| Callaway | 37,000 | 38,500 | 1,500 | 4.1% | $1,076,100 |
| Camden | 20,500 | 19,500 | -1,000 | -4.9% | -$717,400 |
| Cape Girardeau | 43,500 | 35,500 | -8,000 | -18.4% | -$5,739,200 |
| Carroll | 27,000 | 42,000 | 15,000 | 55.6% | $10,761,000 |
| Carter | 7,400 | 7,100 | -300 | -4.1% | -$215,220 |
| Cass | 43,500 | 35,500 | -8,000 | -18.4% | -$5,739,200 |
| Cedar | 43,500 | 41,000 | -2,500 | -5.7% | -$1,793,500 |
| Chariton | 42,500 | 39,500 | -3,000 | -7.1% | -$2,152,200 |
| Christian | 47,000 | 34,000 | -13,000 | -27.7% | -$9,326,200 |
| Clark | 19,400 | 23,500 | 4,100 | 21.1% | $2,941,340 |
| Clay | 23,500 | 27,000 | 3,500 | 14.9% | $2,510,900 |
| Clinton | 41,000 | 25,500 | -15,500 | -37.8% | -$11,119,700 |
| Cole | 40,500 | 35,000 | -5,500 | -13.6% | -$3,945,700 |
| Cooper | 53,000 | 43,000 | -10,000 | -18.9% | -$7,174,000 |
| Crawford | 29,000 | 29,500 | 500 | 1.7% | $358,700 |
| Dade | 57,000 | 61,000 | 4,000 | 7.0% | $2,869,600 |
| Dallas | 52,000 | 50,000 | -2,000 | -3.8% | -$1,434,800 |
| Daviess | 31,000 | 17,600 | -13,400 | -43.2% | -$9,613,160 |
| DeKalb | 46,000 | 26,000 | -20,000 | -43.5% | -$14,348,000 |
| Dent | 25,000 | 29,500 | 4,500 | 18.0% | $3,228,300 |
| Douglas | 40,000 | 42,500 | 2,500 | 6.3% | $1,793,500 |
| Dunklin | 1,600 | 800 | -800 | -50.0% | -$573,920 |
| Franklin | 44,000 | 41,000 | -3,000 | -6.8% | -$2,152,200 |
| Gasconade | 32,000 | 30,000 | -2,000 | -6.3% | -$1,434,800 |
| Gentry | 33,500 | 31,500 | -2,000 | -6.0% | -$1,434,800 |
| Greene | 59,000 | 55,000 | -4,000 | -6.8% | -$2,869,600 |
| Grundy | 22,000 | 16,200 | -5,800 | -26.4% | -$4,160,920 |
| Harrison | 44,000 | 31,500 | -12,500 | -28.4% | -$8,967,500 |

| County | Jan 1, 2012 | Jan 1, 2013 | Change | % Change | Net Worth[1] |
|---|---|---|---|---|---|
| Henry | 59,000 | 55,000 | -4,000 | -6.8% | -$2,869,600 |
| Hickory | 28,500 | 40,000 | 11,500 | 40.4% | $8,250,100 |
| Holt | 6,000 | 3,500 | -2,500 | -41.7% | -$1,793,500 |
| Howard | 24,500 | 25,500 | 1,000 | 4.1% | $717,400 |
| Howell | 88,000 | 75,000 | -13,000 | -14.8% | -$9,326,200 |
| Iron | 10,800 | 8,000 | -2,800 | -25.9% | -$2,008,720 |
| Jackson | 11,000 | 14,000 | 3,000 | 27.3% | $2,152,200 |
| Jasper | 49,000 | 45,000 | -4,000 | -8.2% | -$2,869,600 |
| Jefferson | 8,400 | 8,900 | 500 | 6.0% | $358,700 |
| Johnson | 75,000 | 68,000 | -7,000 | -9.3% | -$5,021,800 |
| Knox | 24,000 | 28,000 | 4,000 | 16.7% | $2,869,600 |
| Laclede | 58,000 | 65,000 | 7,000 | 12.1% | $5,021,800 |
| Lafayette | 33,000 | 30,500 | -2,500 | -7.6% | -$1,793,500 |
| Lawrence | 97,000 | 110,000 | 13,000 | 13.4% | $9,326,200 |
| Lewis | 21,500 | 24,500 | 3,000 | 14.0% | $2,152,200 |
| Lincoln | 16,600 | 23,000 | 6,400 | 38.6% | $4,591,360 |
| Linn | 43,500 | 47,000 | 3,500 | 8.0% | $2,510,900 |
| Livingston | 24,000 | 19,100 | -4,900 | -20.4% | -$3,515,260 |
| Macon | 47,000 | 42,500 | -4,500 | -9.6% | -$3,228,300 |
| Madison | 12,700 | 15,300 | 2,600 | 20.5% | $1,865,240 |
| Maries | 51,000 | 47,500 | -3,500 | -6.9% | -$2,510,900 |
| Marion | 20,000 | 15,300 | -4,700 | -23.5% | -$3,371,780 |
| McDonald | 50,000 | 38,000 | -12,000 | -24.0% | -$8,608,800 |
| Mercer | 21,000 | 22,500 | 1,500 | 7.1% | $1,076,100 |
| Miller | 50,000 | 51,000 | 1,000 | 2.0% | $717,400 |
| Mississippi | 1,200 | 1,100 | -100 | -8.3% | -$71,740 |
| Moniteau | 71,000 | 77,000 | 6,000 | 8.5% | $4,304,400 |
| Monroe | 27,000 | 26,500 | -500 | -1.9% | -$358,700 |
| Montgomery | 20,000 | 24,500 | 4,500 | 22.5% | $3,228,300 |
| Morgan | 43,500 | 47,500 | 4,000 | 9.2% | $2,869,600 |
| New Madrid | 300 | 300 | 0 | 0.0% | $0 |
| Newton | 70,000 | 79,000 | 9,000 | 12.9% | $6,456,600 |
| Nodaway | 64,000 | 43,000 | -21,000 | -32.8% | -$15,065,400 |
| Oregon | 43,000 | 48,000 | 5,000 | 11.6% | $3,587,000 |
| Osage | 59,000 | 57,000 | -2,000 | -3.4% | -$1,434,800 |
| Ozark | 52,000 | 45,000 | -7,000 | -13.5% | -$5,021,800 |
| Pemiscot | 400 | 100 | -300 | -75.0% | -$215,220 |
| Perry | 33,000 | 39,000 | 6,000 | 18.2% | $4,304,400 |
| Pettis | 77,000 | 58,000 | -19,000 | -24.7% | -$13,630,600 |
| Phelps | 25,000 | 22,000 | -3,000 | -12.0% | -$2,152,200 |
| Pike | 34,500 | 35,500 | 1,000 | 2.9% | $717,400 |
| Platte | 12,200 | 9,200 | -3,000 | -24.6% | -$2,152,200 |

| County | Jan 1, 2012 | Jan 1, 2013 | Change | % Change | Net Worth[1] |
|---|---|---|---|---|---|
| Polk | 98,000 | 90,000 | -8,000 | -8.2% | -$5,739,200 |
| Pulaski | 21,000 | 15,700 | -5,300 | -25.2% | -$3,802,220 |
| Putnam | 44,000 | 49,000 | 5,000 | 11.4% | $3,587,000 |
| Ralls | 15,500 | 12,600 | -2,900 | -18.7% | -$2,080,460 |
| Randolph | 29,000 | 22,000 | -7,000 | -24.1% | -$5,021,800 |
| Ray | 40,000 | 25,500 | -14,500 | -36.3% | -$10,402,300 |
| Reynolds | 8,500 | 7,900 | -600 | -7.1% | -$430,440 |
| Ripley | 17,400 | 18,600 | 1,200 | 6.9% | $860,880 |
| Saline | 37,500 | 24,000 | -13,500 | -36.0% | -$9,684,900 |
| Schuyler | 26,500 | 23,000 | -3,500 | -13.2% | -$2,510,900 |
| Scotland | 22,500 | 24,500 | 2,000 | 8.9% | $1,434,800 |
| Scott | 7,300 | 8,200 | 900 | 12.3% | $645,660 |
| Shannon | 18,100 | 16,500 | -1,600 | -8.8% | -$1,147,840 |
| Shelby | 21,000 | 20,500 | -500 | -2.4% | -$358,700 |
| Saint Charles | 6,000 | 6,500 | 500 | 8.3% | $358,700 |
| Saint Clair | 46,500 | 44,000 | -2,500 | -5.4% | -$1,793,500 |
| Saint Francois | 17,200 | 15,800 | -1,400 | -8.1% | -$1,004,360 |
| Saint Louis | 800 | 1,000 | 200 | 25.0% | $143,480 |
| Sainte Genevieve | 30,000 | 19,500 | -10,500 | -35.0% | -$7,532,700 |
| Stoddard | 9,100 | 10,500 | 1,400 | 15.4% | $1,004,360 |
| Stone | 25,000 | 25,000 | 0 | 0.0% | $0 |
| Sullivan | 48,500 | 40,500 | -8,000 | -16.5% | -$5,739,200 |
| Taney | 13,400 | 14,200 | 800 | 6.0% | $573,920 |
| Texas | 63,000 | 67,000 | 4,000 | 6.3% | $2,869,600 |
| Vernon | 67,000 | 63,000 | -4,000 | -6.0% | -$2,869,600 |
| Warren | 15,900 | 11,300 | -4,600 | -28.9% | -$3,300,040 |
| Washington | 19,500 | 16,400 | -3,100 | -15.9% | -$2,223,940 |
| Wayne | 15,400 | 12,700 | -2,700 | -17.5% | -$1,936,980 |
| Webster | 66,000 | 73,000 | 7,000 | 10.6% | $5,021,800 |
| Worth | 20,000 | 13,500 | -6,500 | -32.5% | -$4,663,100 |
| Wright | 67,000 | 69,000 | 2,000 | 3.0% | $1,434,800 |
| **State Total** | **3,950,000** | **3,700,000** | **-250,000** | **-6.3%** | **-$179,350,000** |

[1]Assumes 500 pounds per head at $143.48 per cwt.
Shaded counties have negative change in inventory.
Totals may not add up because of rounding.

**Table B6. Total LFP Payments by County by Year in Million Dollars (2020 Dollars)**
**(Years 2015, 2016, and 2019 are all zero and are excluded from the table.)**

| County | 2011 | 2012 | 2013 | 2014 | 2017 | 2018 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|
| Adair | | $2.993 | $0.872 | | | $1.738 | | $5.603 |
| Andrew | | $1.434 | $0.381 | | $0.001 | $0.695 | | $2.511 |
| Atchison | | $0.686 | | | | $0.264 | | $0.950 |
| Audrain | | $1.214 | | | | $0.084 | | $1.297 |
| Barry | | $9.054 | | | | $2.641 | $2.146 | $13.842 |
| Barton | $0.533 | $3.055 | | | | $1.122 | $0.014 | $4.724 |
| Bates | $0.966 | $7.307 | | | | $0.021 | | $8.294 |
| Benton | | $3.744 | | | | $0.041 | | $3.785 |
| Bollinger | | $3.202 | | | | | | $3.202 |
| Boone | | $1.830 | | | | $0.736 | | $2.566 |
| Buchanan | | $0.882 | $0.009 | | | $0.274 | | $1.165 |
| Butler | | $0.640 | | | | | | $0.640 |
| Caldwell | | $2.052 | $0.531 | | | $1.530 | | $4.113 |
| Callaway | | $3.139 | | | | $1.605 | | $4.744 |
| Camden | | $2.187 | | | | $0.001 | | $2.188 |
| Cape Girardeau | | $3.012 | | | | | | $3.012 |
| Carroll | | $2.050 | $0.518 | | | $1.013 | | $3.581 |
| Carter | | | $0.923 | | | | | $0.923 |
| Cass | $0.004 | $4.712 | | | | $0.365 | | $5.081 |
| Cedar | $0.003 | $4.163 | | | | $1.789 | $0.006 | $5.961 |
| Chariton | | $2.726 | $0.734 | | | $1.234 | | $4.693 |
| Christian | | $3.382 | | | | $0.005 | $1.011 | $4.398 |
| Clark | | $1.201 | $0.319 | | $0.009 | $0.487 | | $2.016 |
| Clay | | $1.379 | $0.000 | | | $0.798 | | $2.177 |
| Clinton | | $2.297 | $0.469 | | | $1.156 | | $3.921 |
| Cole | | $3.254 | | | | $1.521 | | $4.776 |
| Cooper | | $2.834 | | | | $1.450 | | $4.284 |
| Crawford | | $2.600 | | | | | | $2.600 |
| Dade | $0.007 | $6.416 | | | | $2.857 | $3.168 | $12.449 |
| Dallas | | $4.224 | | | | $1.360 | $0.002 | $5.586 |
| Daviess | | $1.660 | $0.454 | | | $1.004 | | $3.119 |
| DeKalb | | $2.652 | $0.709 | | | $1.342 | | $4.703 |
| Dent | | $2.218 | | | | | | $2.218 |
| Douglas | | $5.697 | | | | $0.022 | $0.540 | $6.259 |
| Dunklin | | $0.092 | | | | | | $0.092 |
| Franklin | | $2.697 | | | | | | $2.697 |
| Gasconade | | $2.809 | | | | | | $2.809 |
| Gentry | | $2.979 | $0.790 | | | $1.410 | | $5.179 |
| Greene | | $5.326 | | | | $1.669 | $1.665 | $8.660 |
| Grundy | | $1.372 | $0.340 | | | $0.687 | | $2.399 |

| County | 2011 | 2012 | 2013 | 2014 | 2017 | 2018 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|
| Harrison | | $3.469 | $0.916 | | $0.042 | $1.901 | | $6.328 |
| Henry | $0.019 | $6.143 | | | | $0.034 | | $6.196 |
| Hickory | | $2.909 | | | | $1.190 | | $4.099 |
| Holt | | $0.313 | | | | $0.184 | | $0.497 |
| Howard | | $1.965 | $0.001 | | | $0.838 | | $2.804 |
| Howell | | $7.869 | | | | $0.002 | $0.003 | $7.874 |
| Iron | | $0.987 | | | | | | $0.987 |
| Jackson | | $0.562 | | | | $0.228 | | $0.789 |
| Jasper | $0.004 | $3.783 | | $0.004 | | $1.273 | $1.188 | $6.252 |
| Jefferson | | $0.660 | | | | | | $0.660 |
| Johnson | | $7.381 | | | | $0.687 | | $8.068 |
| Knox | | $1.603 | $0.441 | | | $0.881 | | $2.925 |
| Laclede | | $6.142 | | | | $2.193 | | $8.334 |
| Lafayette | | $1.859 | $0.003 | | | $0.944 | | $2.806 |
| Lawrence | | $6.645 | | | | $2.415 | $2.718 | $11.778 |
| Lewis | | $1.181 | $0.313 | | | $0.424 | | $1.918 |
| Lincoln | | $1.024 | | | | | | $1.024 |
| Linn | | $3.796 | $1.024 | | | $1.848 | | $6.668 |
| Livingston | | $1.020 | $0.263 | | | $0.567 | | $1.850 |
| Macon | | $3.794 | $0.966 | | | $1.874 | | $6.634 |
| Madison | | $1.621 | | | | | | $1.621 |
| Maries | | $4.253 | | | | | | $4.253 |
| Marion | | $1.085 | $0.006 | | | $0.001 | | $1.092 |
| McDonald | | $4.685 | | | | $0.228 | $0.661 | $5.575 |
| Mercer | | $2.404 | $0.625 | | $0.001 | $1.374 | | $4.405 |
| Miller | | $4.614 | | | | $0.016 | | $4.631 |
| Mississippi | | $0.020 | | | | | | $0.020 |
| Moniteau | | $4.879 | | | | $2.422 | | $7.300 |
| Monroe | | $2.045 | $0.534 | | | $0.220 | | $2.798 |
| Montgomery | | $1.242 | | | | $0.017 | | $1.259 |
| Morgan | | $3.631 | | | | $0.299 | | $3.930 |
| New Madrid | | $0.013 | | | | | | $0.013 |
| Newton | | $6.585 | | $0.002 | | $1.550 | $1.143 | $9.280 |
| Nodaway | | $4.911 | $1.320 | | | $2.228 | | $8.459 |
| Oregon | | $6.613 | | | | $0.021 | | $6.635 |
| Osage | | $5.344 | | | | | | $5.344 |
| Ozark | | $6.116 | | | | | $0.006 | $6.122 |
| Pemiscot | | $0.002 | | | | | | $0.002 |
| Perry | | $2.350 | | | | | | $2.350 |
| Pettis | | $4.610 | $0.008 | | | $0.135 | | $4.752 |
| Phelps | | $3.930 | | | | | | $3.930 |
| Pike | | $2.080 | | | | | | $2.080 |

| County | 2011 | 2012 | 2013 | 2014 | 2017 | 2018 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|
| **Platte** | | $1.436 | | | | $0.618 | | $2.055 |
| **Polk** | | $7.871 | | | | $2.733 | $0.062 | $10.666 |
| **Pulaski** | | $1.967 | | | | | | $1.967 |
| **Putnam** | | $3.543 | $0.979 | | $0.025 | $2.027 | | $6.574 |
| **Ralls** | | $1.478 | $0.011 | | | $0.005 | | $1.494 |
| **Randolph** | | $1.878 | $0.515 | | | $0.983 | | $3.376 |
| **Ray** | | $2.772 | $0.004 | | | $1.660 | | $4.437 |
| **Reynolds** | | $0.847 | | | | | | $0.847 |
| **Ripley** | | $2.201 | | | | | | $2.201 |
| **Saint Charles** | | $0.191 | | | | | | $0.191 |
| **Saint Clair** | $0.001 | $3.754 | | | | $1.549 | | $5.303 |
| **Saint Francois** | | $1.352 | | | | | | $1.352 |
| **Saint Louis** | | $0.007 | | | | | | $0.007 |
| **Ste Genevieve** | | $1.195 | | | | | | $1.195 |
| **Saline** | | $1.818 | $0.460 | | | $0.800 | | $3.078 |
| **Schuyler** | | $2.382 | $0.677 | | $0.005 | $1.248 | | $4.313 |
| **Scotland** | | $1.076 | $0.298 | | | $0.636 | | $2.009 |
| **Scott** | | $0.619 | | | | | | $0.619 |
| **Shannon** | | $2.035 | | | | | | $2.035 |
| **Shelby** | | $1.180 | $0.307 | | | $0.029 | | $1.516 |
| **Stoddard** | | $0.811 | | | | | | $0.811 |
| **Stone** | | $3.323 | | | | $0.009 | $0.742 | $4.074 |
| **Sullivan** | | $4.860 | $1.308 | | | $2.794 | | $8.962 |
| **Taney** | | $2.396 | | | | | $0.002 | $2.398 |
| **Texas** | | $6.918 | | | | $0.022 | $0.006 | $6.946 |
| **Vernon** | $0.957 | $6.802 | | | | $0.043 | | $7.802 |
| **Warren** | | $0.500 | | | | | | $0.500 |
| **Washington** | | $1.235 | | | | | | $1.235 |
| **Wayne** | | $1.854 | | | | | | $1.854 |
| **Webster** | | $5.668 | | | | $1.854 | $0.451 | $7.972 |
| **Worth** | | $1.969 | $0.562 | | $0.001 | $1.056 | | $3.588 |
| **Wright** | | $8.401 | | | | $2.727 | $0.003 | $11.131 |
| **State Total** | **$2.493** | **$335.649** | **$18.588** | **$0.007** | **$0.085** | **$77.711** | **$15.538** | **$450.071** |

Totals may not add up because of rounding.

*Source: USDA FSA Missouri State Office*

**Table B7. Relative Potential for Agricultural Drought Impact by County (1-4)**

| County | Non-irrigated Crop Acres | Livestock Inventory | Poultry Inventory | Average Potential Impact Score |
|---|---|---|---|---|
| **Adair** | 3 | 3 | 4 | 3.33 |
| **Andrew** | 3 | 1 | 1 | 1.67 |
| **Atchison** | 4 | 1 | 1 | 2.00 |
| **Audrain** | 4 | 4 | 3 | 3.67 |
| **Barry** | 2 | 4 | 4 | 3.33 |
| **Barton** | 4 | 4 | 4 | 4.00 |
| **Bates** | 4 | 3 | 3 | 3.33 |
| **Benton** | 2 | 3 | 4 | 3.00 |
| **Bollinger** | 2 | 2 | 2 | 2.00 |
| **Boone** | 3 | 2 | 4 | 3.00 |
| **Buchanan** | 3 | 1 | 1 | 1.67 |
| **Butler** | 2 | 1 | 1 | 1.33 |
| **Caldwell** | 3 | 2 | 1 | 2.00 |
| **Callaway** | 3 | 4 | 3 | 3.33 |
| **Camden** | 1 | 2 | 3 | 2.00 |
| **Cape Girardeau** | 3 | 3 | 2 | 2.67 |
| **Carroll** | 4 | 3 | 1 | 2.67 |
| **Carter** | 1 | 1 | 1 | 1.00 |
| **Cass** | 4 | 4 | 3 | 3.67 |
| **Cedar** | 2 | 3 | 2 | 2.33 |
| **Chariton** | 4 | 3 | 1 | 2.67 |
| **Christian** | 1 | 2 | 3 | 2.00 |
| **Clark** | 3 | 2 | 2 | 2.33 |
| **Clay** | 2 | 2 | 2 | 2.00 |
| **Clinton** | 3 | 2 | 3 | 2.67 |
| **Cole** | 2 | 4 | 4 | 3.33 |
| **Cooper** | 4 | 3 | 4 | 3.67 |
| **Crawford** | 1 | 2 | 3 | 2.00 |
| **Dade** | 2 | 3 | 4 | 3.00 |
| **Dallas** | 1 | 3 | 4 | 2.67 |
| **Daviess** | 4 | 4 | 4 | 4.00 |
| **DeKalb** | 3 | 2 | 2 | 2.33 |
| **Dent** | 1 | 2 | 3 | 2.00 |
| **Douglas** | 1 | 3 | 2 | 2.00 |
| **Dunklin** | 3 | 1 | 1 | 1.67 |
| **Franklin** | 3 | 4 | 3 | 3.33 |
| **Gasconade** | 2 | 2 | 2 | 2.00 |
| **Gentry** | 3 | 2 | 2 | 2.33 |
| **Greene** | 2 | 3 | 4 | 3.00 |
| **Grundy** | 3 | 1 | 3 | 2.33 |
| **Harrison** | 4 | 2 | 3 | 3.00 |
| **Henry** | 4 | 4 | 2 | 3.33 |
| **Hickory** | 1 | 3 | 1 | 1.67 |
| **Holt** | 3 | 1 | 1 | 1.67 |
| **Howard** | 3 | 2 | 3 | 2.67 |

| County | Non-irrigated Crop Acres | Livestock Inventory | Poultry Inventory | Average Potential Impact Score |
|---|---|---|---|---|
| **Howell** | 1 | 4 | 3 | 2.67 |
| **Iron** | 1 | 1 | 1 | 1.00 |
| **Jackson** | 2 | 1 | 3 | 2.00 |
| **Jasper** | 3 | 4 | 4 | 3.67 |
| **Jefferson** | 1 | 1 | 4 | 2.00 |
| **Johnson** | 4 | 3 | 1 | 2.67 |
| **Knox** | 4 | 3 | 4 | 3.67 |
| **Laclede** | 2 | 3 | 3 | 2.67 |
| **Lafayette** | 4 | 3 | 2 | 3.00 |
| **Lawrence** | 3 | 4 | 4 | 3.67 |
| **Lewis** | 4 | 2 | 1 | 2.33 |
| **Lincoln** | 4 | 2 | 1 | 2.33 |
| **Linn** | 3 | 3 | 2 | 2.67 |
| **Livingston** | 4 | 2 | 3 | 3.00 |
| **Macon** | 4 | 3 | 3 | 2.67 |
| **Madison** | 1 | 1 | 1 | 3.33 |
| **Maries** | 1 | 3 | 3 | 1.00 |
| **Marion** | 3 | 4 | 1 | 2.33 |
| **McDonald** | 1 | 3 | 4 | 2.67 |
| **Mercer** | 2 | 2 | 1 | 1.67 |
| **Miller** | 1 | 4 | 4 | 3.00 |
| **Mississippi** | 3 | 1 | 1 | 1.67 |
| **Moniteau** | 2 | 4 | 4 | 3.33 |
| **Monroe** | 4 | 4 | 3 | 3.67 |
| **Montgomery** | 4 | 2 | 2 | 2.67 |
| **Morgan** | 2 | 4 | 4 | 3.33 |
| **New Madrid** | 3 | 1 | 1 | 1.67 |
| **Newton** | 2 | 4 | 4 | 3.33 |
| **Nodaway** | 4 | 4 | 2 | 3.33 |
| **Oregon** | 1 | 3 | 2 | 2.00 |
| **Osage** | 2 | 4 | 4 | 3.33 |
| **Ozark** | 1 | 3 | 2 | 2.00 |
| **Pemiscot** | 4 | 1 | 1 | 2.00 |
| **Perry** | 3 | 3 | 2 | 2.67 |
| **Pettis** | 4 | 4 | 4 | 4.00 |
| **Phelps** | 1 | 2 | 2 | 1.67 |
| **Pike** | 4 | 4 | 3 | 3.67 |
| **Platte** | 2 | 1 | 1 | 1.33 |
| **Polk** | 2 | 4 | 4 | 3.33 |
| **Pulaski** | 1 | 1 | 3 | 1.67 |
| **Putnam** | 2 | 4 | 1 | 2.33 |
| **Ralls** | 4 | 1 | 1 | 2.00 |
| **Randolph** | 2 | 2 | 3 | 2.33 |
| **Ray** | 3 | 2 | 3 | 2.67 |
| **Reynolds** | 1 | 1 | 2 | 1.33 |
| **Ripley** | 1 | 2 | 1 | 1.33 |

| County | Non-irrigated Crop Acres | Livestock Inventory | Poultry Inventory | Average Potential Impact Score |
|---|---|---|---|---|
| **St Charles** | 3 | 2 | 2 | 2.33 |
| **St Clair** | 2 | 3 | 2 | 2.33 |
| **St Francois** | 1 | 1 | 3 | 1.67 |
| **St Louis** | 1 | 1 | 1 | 1.67 |
| **Ste Genevieve** | 2 | 1 | 2 | 1.00 |
| **Saline** | 4 | 4 | 2 | 3.33 |
| **Schuyler** | 2 | 2 | 1 | 1.67 |
| **Scotland** | 3 | 4 | 2 | 3.00 |
| **Scott** | 4 | 1 | 4 | 3.00 |
| **Shannon** | 1 | 2 | 2 | 1.67 |
| **Shelby** | 4 | 3 | 1 | 2.67 |
| **Stoddard** | 3 | 1 | 4 | 2.67 |
| **Stone** | 1 | 2 | 4 | 2.33 |
| **Sullivan** | 3 | 4 | 2 | 3.00 |
| **Taney** | 1 | 1 | 3 | 1.67 |
| **Texas** | 2 | 3 | 3 | 2.67 |
| **Vernon** | 4 | 4 | 4 | 4.00 |
| **Warren** | 2 | 1 | 2 | 1.67 |
| **Washington** | 1 | 1 | 3 | 1.67 |
| **Wayne** | 1 | 1 | 2 | 1.33 |
| **Webster** | 2 | 4 | 4 | 3.33 |
| **Worth** | 1 | 1 | 1 | 1.00 |
| **Wright** | 2 | 3 | 4 | 3.00 |

(1 is low relative impact potential, 4 is high relative impact potential)

**Table B8. Counties Ranked by Relative Potential for Agricultural Drought Impact**

| County | Non-irrigated Crop Acres | Livestock Inventory | Poultry Inventory | Average Potential Impact Score |
|---|---|---|---|---|
| **Barton** | 4 | 4 | 4 | 4.00 |
| **Daviess** | 4 | 4 | 4 | 4.00 |
| **Pettis** | 4 | 4 | 4 | 4.00 |
| **Vernon** | 4 | 4 | 4 | 4.00 |
| **Audrain** | 4 | 4 | 3 | 3.67 |
| **Cass** | 4 | 4 | 3 | 3.67 |
| **Cooper** | 4 | 3 | 4 | 3.67 |
| **Jasper** | 3 | 4 | 4 | 3.67 |
| **Knox** | 4 | 3 | 4 | 3.67 |
| **Lawrence** | 3 | 4 | 4 | 3.67 |
| **Monroe** | 4 | 4 | 3 | 3.67 |
| **Pike** | 4 | 4 | 3 | 3.67 |
| **Adair** | 3 | 3 | 4 | 3.33 |
| **Barry** | 2 | 4 | 4 | 3.33 |
| **Bates** | 4 | 3 | 3 | 3.33 |
| **Callaway** | 3 | 4 | 3 | 3.33 |
| **Cole** | 2 | 4 | 4 | 3.33 |
| **Franklin** | 3 | 4 | 3 | 3.33 |
| **Henry** | 4 | 4 | 2 | 3.33 |
| **Macon** | 4 | 3 | 3 | 3.33 |
| **Moniteau** | 2 | 4 | 4 | 3.33 |
| **Morgan** | 2 | 4 | 4 | 3.33 |
| **Newton** | 2 | 4 | 4 | 3.33 |
| **Nodaway** | 4 | 4 | 2 | 3.33 |
| **Osage** | 2 | 4 | 4 | 3.33 |
| **Polk** | 2 | 4 | 4 | 3.33 |
| **Saline** | 4 | 4 | 2 | 3.33 |
| **Webster** | 2 | 4 | 4 | 3.33 |
| **Benton** | 2 | 3 | 4 | 3.00 |
| **Boone** | 3 | 2 | 4 | 3.00 |
| **Dade** | 2 | 3 | 4 | 3.00 |
| **Greene** | 2 | 3 | 4 | 3.00 |
| **Harrison** | 4 | 2 | 3 | 3.00 |
| **Lafayette** | 4 | 3 | 2 | 3.00 |
| **Livingston** | 4 | 2 | 3 | 3.00 |
| **Miller** | 1 | 4 | 4 | 3.00 |
| **Scotland** | 3 | 4 | 2 | 3.00 |
| **Scott** | 4 | 1 | 4 | 3.00 |
| **Sullivan** | 3 | 4 | 2 | 3.00 |
| **Wright** | 2 | 3 | 4 | 3.00 |
| **Cape Girardeau** | 3 | 3 | 2 | 2.67 |
| **Carroll** | 4 | 3 | 1 | 2.67 |
| **Chariton** | 4 | 3 | 1 | 2.67 |
| **Clinton** | 3 | 2 | 3 | 2.67 |
| **Dallas** | 1 | 3 | 4 | 2.67 |
| **Howard** | 3 | 2 | 3 | 2.67 |

| County | Non-irrigated Crop Acres | Livestock Inventory | Poultry Inventory | Average Potential Impact Score |
|---|---|---|---|---|
| Howell | 1 | 4 | 3 | 2.67 |
| Johnson | 4 | 3 | 1 | 2.67 |
| Laclede | 2 | 3 | 3 | 2.67 |
| Linn | 3 | 3 | 2 | 2.67 |
| McDonald | 1 | 3 | 4 | 2.67 |
| Marion | 3 | 4 | 1 | 2.67 |
| Montgomery | 4 | 2 | 2 | 2.67 |
| Perry | 3 | 3 | 2 | 2.67 |
| Ray | 3 | 2 | 3 | 2.67 |
| Shelby | 4 | 3 | 1 | 2.67 |
| Stoddard | 3 | 1 | 4 | 2.67 |
| Texas | 2 | 3 | 3 | 2.67 |
| Cedar | 2 | 3 | 2 | 2.33 |
| Clark | 3 | 2 | 2 | 2.33 |
| DeKalb | 3 | 2 | 2 | 2.33 |
| Gentry | 3 | 2 | 2 | 2.33 |
| Grundy | 3 | 1 | 3 | 2.33 |
| Lewis | 4 | 2 | 1 | 2.33 |
| Lincoln | 4 | 2 | 1 | 2.33 |
| Maries | 1 | 3 | 3 | 2.33 |
| Putnam | 2 | 4 | 1 | 2.33 |
| Randolph | 2 | 2 | 3 | 2.33 |
| St Charles | 3 | 2 | 2 | 2.33 |
| St Clair | 2 | 3 | 2 | 2.33 |
| Stone | 1 | 2 | 4 | 2.33 |
| Atchison | 4 | 1 | 1 | 2.00 |
| Bollinger | 2 | 2 | 2 | 2.00 |
| Caldwell | 3 | 2 | 1 | 2.00 |
| Camden | 1 | 2 | 3 | 2.00 |
| Christian | 1 | 2 | 3 | 2.00 |
| Clay | 2 | 2 | 2 | 2.00 |
| Crawford | 1 | 2 | 3 | 2.00 |
| Dent | 1 | 2 | 3 | 2.00 |
| Douglas | 1 | 3 | 2 | 2.00 |
| Gasconade | 2 | 2 | 2 | 2.00 |
| Jackson | 2 | 1 | 3 | 2.00 |
| Jefferson | 1 | 1 | 4 | 2.00 |
| Oregon | 1 | 3 | 2 | 2.00 |
| Ozark | 1 | 3 | 2 | 2.00 |
| Pemiscot | 4 | 1 | 1 | 2.00 |
| Ralls | 4 | 1 | 1 | 2.00 |
| Andrew | 3 | 1 | 1 | 1.67 |
| Buchanan | 3 | 1 | 1 | 1.67 |
| Dunklin | 3 | 1 | 1 | 1.67 |
| Hickory | 1 | 3 | 1 | 1.67 |
| Holt | 3 | 1 | 1 | 1.67 |
| Mercer | 2 | 2 | 1 | 1.67 |

| County | Non-irrigated Crop Acres | Livestock Inventory | Poultry Inventory | Average Potential Impact Score |
|---|---|---|---|---|
| **Mississippi** | 3 | 1 | 1 | 1.67 |
| **New Madrid** | 3 | 1 | 1 | 1.67 |
| **Phelps** | 1 | 2 | 2 | 1.67 |
| **Pulaski** | 1 | 1 | 3 | 1.67 |
| **St Francois** | 1 | 1 | 3 | 1.67 |
| **Ste Genevieve** | 2 | 1 | 2 | 1.67 |
| **Schuyler** | 2 | 2 | 1 | 1.67 |
| **Shannon** | 1 | 2 | 2 | 1.67 |
| **Taney** | 1 | 1 | 3 | 1.67 |
| **Warren** | 2 | 1 | 2 | 1.67 |
| **Washington** | 1 | 1 | 3 | 1.67 |
| **Butler** | 2 | 1 | 1 | 1.33 |
| **Platte** | 2 | 1 | 1 | 1.33 |
| **Reynolds** | 1 | 1 | 2 | 1.33 |
| **Ripley** | 1 | 2 | 1 | 1.33 |
| **Wayne** | 1 | 1 | 2 | 1.33 |
| **Carter** | 1 | 1 | 1 | 1.00 |
| **Iron** | 1 | 1 | 1 | 1.00 |
| **Madison** | 1 | 1 | 1 | 1.00 |
| **St Louis** | 1 | 1 | 1 | 1.00 |
| **Worth** | 1 | 1 | 1 | 1.00 |

(1 is low relative impact potential, 4 is high relative impact potential)

**Table B9. Relative Potential for Drought Impact on Municipal Water Supply by County**

| County | Served Population | Municipal MGD | Average Potential Impact |
|---|---|---|---|
| Adair | 3 | 3 | 3.0 |
| Andrew | 3 | 2 | 2.5 |
| Atchison | 1 | 1 | 1.0 |
| Audrain | 3 | 3 | 3.0 |
| Barry | 3 | 4 | 3.5 |
| Barton | 2 | 2 | 2.0 |
| Bates | 3 | 2 | 2.5 |
| Benton | 1 | 1 | 1.0 |
| Bollinger | 1 | 1 | 1.0 |
| Boone | 4 | 4 | 4.0 |
| Buchanan | 4 | 4 | 4.0 |
| Butler | 4 | 3 | 3.5 |
| Caldwell | 1 | 1 | 1.0 |
| Callaway | 4 | 4 | 4.0 |
| Camden | 4 | 4 | 4.0 |
| Cape Girardeau | 4 | 4 | 4.0 |
| Carroll | 2 | 2 | 2.0 |
| Carter | 1 | 1 | 1.0 |
| Cass | 4 | 4 | 4.0 |
| Cedar | 2 | 2 | 2.0 |
| Chariton | 1 | 1 | 1.0 |
| Christian | 4 | 4 | 4.0 |
| Clark | 2 | 2 | 2.0 |
| Clay | 4 | 4 | 4.0 |
| Clinton | 3 | 3 | 3.0 |
| Cole | 4 | 4 | 4.0 |
| Cooper | 3 | 3 | 3.0 |
| Crawford | 2 | 2 | 2.0 |
| Dade | 1 | 1 | 1.0 |
| Dallas | 1 | 1 | 1.0 |
| Daviess | 2 | 2 | 2.0 |
| DeKalb | 3 | 3 | 3.0 |
| Dent | 2 | 2 | 2.0 |
| Douglas | 1 | 1 | 1.0 |
| Dunklin | 4 | 3 | 3.5 |
| Franklin | 4 | 4 | 4.0 |

**Table B10. Counties Ranked by Relative Potential for Drought Impact on Municipal Water Supply**

| County | Served Population | Municipal MGD | Average Potential Impact |
|---|---|---|---|
| Boone | 4 | 4 | 4.0 |
| Buchanan | 4 | 4 | 4.0 |
| Callaway | 4 | 4 | 4.0 |
| Camden | 4 | 4 | 4.0 |
| Cape Girardeau | 4 | 4 | 4.0 |
| Cass | 4 | 4 | 4.0 |
| Christian | 4 | 4 | 4.0 |
| Clay | 4 | 4 | 4.0 |
| Cole | 4 | 4 | 4.0 |
| Franklin | 4 | 4 | 4.0 |
| Greene | 4 | 4 | 4.0 |
| Jackson | 4 | 4 | 4.0 |
| Jasper | 4 | 4 | 4.0 |
| Jefferson | 4 | 4 | 4.0 |
| Johnson | 4 | 4 | 4.0 |
| Laclede | 4 | 4 | 4.0 |
| Lafayette | 4 | 4 | 4.0 |
| Pettis | 4 | 4 | 4.0 |
| Platte | 4 | 4 | 4.0 |
| Pulaski | 4 | 4 | 4.0 |
| Scott | 4 | 4 | 4.0 |
| St Charles | 4 | 4 | 4.0 |
| St Francois | 4 | 4 | 4.0 |
| St Louis | 4 | 4 | 4.0 |
| Taney | 4 | 4 | 4.0 |
| Butler | 4 | 3 | 3.5 |
| Dunklin | 4 | 3 | 3.5 |
| Lincoln | 4 | 3 | 3.5 |
| Phelps | 4 | 3 | 3.5 |
| Barry | 3 | 4 | 3.5 |
| Marion | 3 | 4 | 3.5 |
| Newton | 3 | 4 | 3.5 |
| Adair | 3 | 3 | 3.0 |
| Audrain | 3 | 3 | 3.0 |
| Clinton | 3 | 3 | 3.0 |
| Cooper | 3 | 3 | 3.0 |

| County | Served Population | Municipal MGD | Average Potential Impact |
|---|---|---|---|
| Gasconade | 2 | 2 | 2.0 |
| Gentry | 2 | 1 | 1.5 |
| Greene | 4 | 4 | 4.0 |
| Grundy | 2 | 3 | 2.5 |
| Harrison | 2 | 2 | 2.0 |
| Henry | 3 | 3 | 3.0 |
| Hickory | 1 | 1 | 1.0 |
| Holt | 1 | 1 | 1.0 |
| Howard | 2 | 2 | 2.0 |
| Howell | 3 | 3 | 3.0 |
| Iron | 1 | 1 | 1.0 |
| Jackson | 4 | 4 | 4.0 |
| Jasper | 4 | 4 | 4.0 |
| Jefferson | 4 | 4 | 4.0 |
| Johnson | 4 | 4 | 4.0 |
| Knox | 1 | 1 | 1.0 |
| Laclede | 4 | 4 | 4.0 |
| Lafayette | 4 | 4 | 4.0 |
| Lawrence | 3 | 3 | 3.0 |
| Lewis | 1 | 1 | 1.0 |
| Lincoln | 4 | 3 | 3.5 |
| Linn | 2 | 2 | 2.0 |
| Livingston | 3 | 3 | 3.0 |
| Macon | 3 | 3 | 3.0 |
| Madison | 2 | 2 | 2.0 |
| Maries | 1 | 1 | 1.0 |
| Marion | 3 | 4 | 3.5 |
| McDonald | 2 | 3 | 2.5 |
| Mercer | 1 | 1 | 1.0 |
| Miller | 2 | 2 | 2.0 |
| Mississippi | 3 | 3 | 3.0 |
| Moniteau | 2 | 2 | 2.0 |
| Monroe | 2 | 2 | 2.0 |
| Montgomery | 2 | 1 | 1.5 |
| Morgan | 2 | 2 | 2.0 |
| New Madrid | 2 | 3 | 2.5 |
| Newton | 3 | 4 | 3.5 |
| Nodaway | 3 | 3 | 3.0 |
| Oregon | 1 | 2 | 1.5 |
| Osage | 1 | 1 | 1.0 |

| County | Served Population | Municipal MGD | Average Potential Impact |
|---|---|---|---|
| DeKalb | 3 | 3 | 3.0 |
| Henry | 3 | 3 | 3.0 |
| Howell | 3 | 3 | 3.0 |
| Lawrence | 3 | 3 | 3.0 |
| Livingston | 3 | 3 | 3.0 |
| Macon | 3 | 3 | 3.0 |
| Mississippi | 3 | 3 | 3.0 |
| Nodaway | 3 | 3 | 3.0 |
| Pemiscot | 3 | 3 | 3.0 |
| Randolph | 3 | 3 | 3.0 |
| Ray | 3 | 3 | 3.0 |
| Saline | 3 | 3 | 3.0 |
| Stoddard | 3 | 3 | 3.0 |
| Texas | 3 | 3 | 3.0 |
| Vernon | 3 | 3 | 3.0 |
| Warren | 3 | 3 | 3.0 |
| Andrew | 3 | 2 | 2.5 |
| Bates | 3 | 2 | 2.5 |
| Pike | 3 | 2 | 2.5 |
| Polk | 3 | 2 | 2.5 |
| Webster | 3 | 2 | 2.5 |
| Grundy | 2 | 3 | 2.5 |
| McDonald | 2 | 3 | 2.5 |
| New Madrid | 2 | 3 | 2.5 |
| Stone | 2 | 3 | 2.5 |
| Barton | 2 | 2 | 2.0 |
| Carroll | 2 | 2 | 2.0 |
| Cedar | 2 | 2 | 2.0 |
| Clark | 2 | 2 | 2.0 |
| Crawford | 2 | 2 | 2.0 |
| Daviess | 2 | 2 | 2.0 |
| Dent | 2 | 2 | 2.0 |
| Gasconade | 2 | 2 | 2.0 |
| Harrison | 2 | 2 | 2.0 |
| Howard | 2 | 2 | 2.0 |
| Linn | 2 | 2 | 2.0 |
| Madison | 2 | 2 | 2.0 |
| Miller | 2 | 2 | 2.0 |
| Moniteau | 2 | 2 | 2.0 |
| Monroe | 2 | 2 | 2.0 |

| County | Served Population | Municipal MGD | Average Potential Impact |
|---|---|---|---|
| Ozark | 1 | 1 | 1.0 |
| Pemiscot | 3 | 3 | 3.0 |
| Perry | 2 | 2 | 2.0 |
| Pettis | 4 | 4 | 4.0 |
| Phelps | 4 | 3 | 3.5 |
| Pike | 3 | 2 | 2.5 |
| Platte | 4 | 4 | 4.0 |
| Polk | 3 | 2 | 2.5 |
| Pulaski | 4 | 4 | 4.0 |
| Putnam | 1 | 1 | 1.0 |
| Ralls | 2 | 2 | 2.0 |
| Randolph | 3 | 3 | 3.0 |
| Ray | 3 | 3 | 3.0 |
| Reynolds | 1 | 1 | 1.0 |
| Ripley | 2 | 2 | 2.0 |
| St Charles | 4 | 4 | 4.0 |
| St Clair | 1 | 1 | 1.0 |
| St Francois | 4 | 4 | 4.0 |
| St Louis | 4 | 4 | 4.0 |
| Ste Genevieve | 2 | 2 | 2.0 |
| Saline | 3 | 3 | 3.0 |
| Schuyler | 1 | 1 | 1.0 |
| Scotland | 1 | 1 | 1.0 |
| Scott | 4 | 4 | 4.0 |
| Shannon | 1 | 1 | 1.0 |
| Shelby | 1 | 1 | 1.0 |
| Stoddard | 3 | 3 | 3.0 |
| Stone | 2 | 3 | 2.5 |
| Sullivan | 2 | 1 | 1.5 |
| Taney | 4 | 4 | 4.0 |
| Texas | 3 | 3 | 3.0 |
| Vernon | 3 | 3 | 3.0 |
| Warren | 3 | 3 | 3.0 |
| Washington | 1 | 2 | 1.5 |
| Wayne | 1 | 2 | 1.5 |
| Webster | 3 | 2 | 2.5 |
| Worth | 1 | 1 | 1.0 |
| Wright | 2 | 2 | 2.0 |

| County | Served Population | Municipal MGD | Average Potential Impact |
|---|---|---|---|
| Morgan | 2 | 2 | 2.0 |
| Perry | 2 | 2 | 2.0 |
| Ralls | 2 | 2 | 2.0 |
| Ripley | 2 | 2 | 2.0 |
| Ste Genevieve | 2 | 2 | 2.0 |
| Wright | 2 | 2 | 2.0 |
| Gentry | 2 | 1 | 1.5 |
| Montgomery | 2 | 1 | 1.5 |
| Sullivan | 2 | 1 | 1.5 |
| Oregon | 1 | 2 | 1.5 |
| Washington | 1 | 2 | 1.5 |
| Wayne | 1 | 2 | 1.5 |
| Atchison | 1 | 1 | 1.0 |
| Benton | 1 | 1 | 1.0 |
| Bollinger | 1 | 1 | 1.0 |
| Caldwell | 1 | 1 | 1.0 |
| Carter | 1 | 1 | 1.0 |
| Chariton | 1 | 1 | 1.0 |
| Dade | 1 | 1 | 1.0 |
| Dallas | 1 | 1 | 1.0 |
| Douglas | 1 | 1 | 1.0 |
| Hickory | 1 | 1 | 1.0 |
| Holt | 1 | 1 | 1.0 |
| Iron | 1 | 1 | 1.0 |
| Knox | 1 | 1 | 1.0 |
| Lewis | 1 | 1 | 1.0 |
| Maries | 1 | 1 | 1.0 |
| Mercer | 1 | 1 | 1.0 |
| Osage | 1 | 1 | 1.0 |
| Ozark | 1 | 1 | 1.0 |
| Putnam | 1 | 1 | 1.0 |
| Reynolds | 1 | 1 | 1.0 |
| Schuyler | 1 | 1 | 1.0 |
| Scotland | 1 | 1 | 1.0 |
| Shannon | 1 | 1 | 1.0 |
| Shelby | 1 | 1 | 1.0 |
| St Clair | 1 | 1 | 1.0 |
| Worth | 1 | 1 | 1.0 |

(1 is low relative impact potential, 4 is high relative impact potential)

**Table B11. Relative Potential for Drought Impact to Industry by County**

| County | Industry | Mining | Average Potential Impact Score |
|---|---|---|---|
| Adair | 1 | 3 | 2.0 |
| Andrew | 1 | 4 | 2.5 |
| Atchison | 1 | 1 | 1.0 |
| Audrain | 2 | 2 | 2.0 |
| Barry | 4 | 4 | 4.0 |
| Barton | 1 | 1 | 1.0 |
| Bates | 1 | 2 | 1.5 |
| Benton | 1 | 2 | 1.5 |
| Bollinger | 1 | 3 | 2.0 |
| Boone | 2 | 4 | 3.0 |
| Buchanan | 3 | 2 | 2.5 |
| Butler | 1 | 3 | 2.0 |
| Caldwell | 1 | 2 | 1.5 |
| Callaway | 3 | 4 | 3.5 |
| Camden | 2 | 3 | 2.5 |
| Cape Girardeau | 4 | 4 | 4.0 |
| Carroll | 2 | 2 | 2.0 |
| Carter | 1 | 1 | 1.0 |
| Cass | 2 | 3 | 2.5 |
| Cedar | 2 | 1 | 1.5 |
| Chariton | 1 | 1 | 1.0 |
| Christian | 2 | 3 | 2.5 |
| Clark | 1 | 1 | 1.0 |
| Clay | 4 | 4 | 4.0 |
| Clinton | 1 | 1 | 1.0 |
| Cole | 1 | 3 | 2.0 |
| Cooper | 1 | 2 | 1.5 |
| Crawford | 2 | 4 | 3.0 |
| Dade | 1 | 1 | 1.0 |
| Dallas | 1 | 2 | 1.5 |
| Daviess | 1 | 3 | 2.0 |
| De Kalb | 1 | 1 | 1.0 |
| Dent | 1 | 2 | 1.5 |
| Douglas | 1 | 3 | 2.0 |
| Dunklin | 1 | 1 | 1.0 |
| Franklin | 2 | 4 | 3.0 |
| Gasconade | 1 | 3 | 2.0 |
| Gentry | 1 | 2 | 1.5 |

**Table B12. Counties Ranked by Relative Potential for Drought Impact to Industry**

| County | Industry | Mining | Average Potential Impact Score |
|---|---|---|---|
| Barry | 4 | 4 | 4.0 |
| Cape Girardeau | 4 | 4 | 4.0 |
| Clay | 4 | 4 | 4.0 |
| Jackson | 4 | 4 | 4.0 |
| Jasper | 4 | 4 | 4.0 |
| Ste. Genevieve | 4 | 4 | 4.0 |
| Taney | 4 | 4 | 4.0 |
| Callaway | 3 | 4 | 3.5 |
| Greene | 3 | 4 | 3.5 |
| Jefferson | 3 | 4 | 3.5 |
| Pettis | 4 | 3 | 3.5 |
| St. Charles | 3 | 4 | 3.5 |
| Stoddard | 3 | 4 | 3.5 |
| Boone | 2 | 4 | 3.0 |
| Crawford | 2 | 4 | 3.0 |
| Franklin | 2 | 4 | 3.0 |
| Iron | 2 | 4 | 3.0 |
| Lincoln | 2 | 4 | 3.0 |
| Marion | 4 | 2 | 3.0 |
| McDonald | 4 | 2 | 3.0 |
| Osage | 2 | 4 | 3.0 |
| Pike | 3 | 3 | 3.0 |
| Ralls | 2 | 4 | 3.0 |
| Washington | 4 | 2 | 3.0 |
| Andrew | 1 | 4 | 2.5 |
| Buchanan | 3 | 2 | 2.5 |
| Camden | 2 | 3 | 2.5 |
| Cass | 2 | 3 | 2.5 |
| Christian | 2 | 3 | 2.5 |
| Johnson | 2 | 3 | 2.5 |
| Montgomery | 1 | 4 | 2.5 |
| Morgan | 1 | 4 | 2.5 |
| New Madrid | 4 | 1 | 2.5 |
| Newton | 2 | 3 | 2.5 |
| Phelps | 2 | 3 | 2.5 |
| Platte | 1 | 4 | 2.5 |
| Reynolds | 1 | 4 | 2.5 |
| Saline | 2 | 3 | 2.5 |

| County | Industry | Mining | Average Potential Impact Score |
|---|---|---|---|
| Greene | 3 | 4 | 3.5 |
| Grundy | 1 | 1 | 1.0 |
| Harrison | 1 | 3 | 2.0 |
| Henry | 1 | 3 | 2.0 |
| Hickory | 1 | 1 | 1.0 |
| Holt | 2 | 1 | 1.5 |
| Howard | 1 | 2 | 1.5 |
| Howell | 1 | 3 | 2.0 |
| Iron | 2 | 4 | 3.0 |
| Jackson | 4 | 4 | 4.0 |
| Jasper | 4 | 4 | 4.0 |
| Jefferson | 3 | 4 | 3.5 |
| Johnson | 2 | 3 | 2.5 |
| Knox | 1 | 2 | 1.5 |
| Laclede | 1 | 2 | 1.5 |
| Lafayette | 1 | 2 | 1.5 |
| Lawrence | 2 | 1 | 1.5 |
| Lewis | 1 | 1 | 1.0 |
| Lincoln | 2 | 4 | 3.0 |
| Linn | 1 | 1 | 1.0 |
| Livingston | 1 | 1 | 1.0 |
| Macon | 3 | 1 | 2.0 |
| Madison | 1 | 1 | 1.0 |
| Maries | 2 | 1 | 1.5 |
| Marion | 4 | 2 | 3.0 |
| McDonald | 4 | 2 | 3.0 |
| Mercer | 2 | 1 | 1.5 |
| Miller | 1 | 2 | 1.5 |
| Mississippi | 1 | 1 | 1.0 |
| Moniteau | 3 | 1 | 2.0 |
| Monroe | 1 | 2 | 1.5 |
| Montgomery | 1 | 4 | 2.5 |
| Morgan | 1 | 4 | 2.5 |
| New Madrid | 4 | 1 | 2.5 |
| Newton | 2 | 3 | 2.5 |
| Nodaway | 1 | 1 | 1.0 |
| Oregon | 1 | 1 | 1.0 |
| Osage | 2 | 4 | 3.0 |
| Ozark | 1 | 2 | 1.5 |
| Pemiscot | 1 | 1 | 1.0 |

| County | Industry | Mining | Average Potential Impact Score |
|---|---|---|---|
| Scott | 2 | 3 | 2.5 |
| St. Francois | 1 | 4 | 2.5 |
| St. Louis | 1 | 4 | 2.5 |
| Texas | 3 | 2 | 2.5 |
| Warren | 3 | 2 | 2.5 |
| Wright | 2 | 3 | 2.5 |
| Adair | 1 | 3 | 2.0 |
| Audrain | 2 | 2 | 2.0 |
| Bollinger | 1 | 3 | 2.0 |
| Butler | 1 | 3 | 2.0 |
| Carroll | 2 | 2 | 2.0 |
| Cole | 1 | 3 | 2.0 |
| Daviess | 1 | 3 | 2.0 |
| Douglas | 1 | 3 | 2.0 |
| Gasconade | 1 | 3 | 2.0 |
| Harrison | 1 | 3 | 2.0 |
| Henry | 1 | 3 | 2.0 |
| Howell | 1 | 3 | 2.0 |
| Macon | 3 | 1 | 2.0 |
| Moniteau | 3 | 1 | 2.0 |
| Polk | 1 | 3 | 2.0 |
| Randolph | 1 | 3 | 2.0 |
| Ripley | 1 | 3 | 2.0 |
| Shannon | 1 | 3 | 2.0 |
| Sullivan | 3 | 1 | 2.0 |
| Wayne | 1 | 3 | 2.0 |
| Bates | 1 | 2 | 1.5 |
| Benton | 1 | 2 | 1.5 |
| Caldwell | 1 | 2 | 1.5 |
| Cedar | 2 | 1 | 1.5 |
| Cooper | 1 | 2 | 1.5 |
| Dallas | 1 | 2 | 1.5 |
| Dent | 1 | 2 | 1.5 |
| Gentry | 1 | 2 | 1.5 |
| Holt | 2 | 1 | 1.5 |
| Howard | 1 | 2 | 1.5 |
| Knox | 1 | 2 | 1.5 |
| Laclede | 1 | 2 | 1.5 |
| Lafayette | 1 | 2 | 1.5 |
| Lawrence | 2 | 1 | 1.5 |

| County | Industry | Mining | Average Potential Impact Score |
|---|---|---|---|
| Perry | 1 | 2 | 1.5 |
| Pettis | 4 | 3 | 3.5 |
| Phelps | 2 | 3 | 2.5 |
| Pike | 3 | 3 | 3.0 |
| Platte | 1 | 4 | 2.5 |
| Polk | 1 | 3 | 2.0 |
| Pulaski | 1 | 2 | 1.5 |
| Putnam | 1 | 1 | 1.0 |
| Ralls | 2 | 4 | 3.0 |
| Randolph | 1 | 3 | 2.0 |
| Ray | 1 | 2 | 1.5 |
| Reynolds | 1 | 4 | 2.5 |
| Ripley | 1 | 3 | 2.0 |
| Saline | 2 | 3 | 2.5 |
| Schuyler | 1 | 1 | 1.0 |
| Scotland | 1 | 1 | 1.0 |
| Scott | 2 | 3 | 2.5 |
| Shannon | 1 | 3 | 2.0 |
| Shelby | 1 | 2 | 1.5 |
| St. Charles | 3 | 4 | 3.5 |
| St. Clair | 1 | 1 | 1.0 |
| St. Francois | 1 | 4 | 2.5 |
| St. Louis | 1 | 4 | 2.5 |
| Ste. Genevieve | 4 | 4 | 4.0 |
| Stoddard | 3 | 4 | 3.5 |
| Stone | 1 | 2 | 1.5 |
| Sullivan | 3 | 1 | 2.0 |
| Taney | 4 | 4 | 4.0 |
| Texas | 3 | 2 | 2.5 |
| Vernon | 1 | 1 | 1.0 |
| Warren | 3 | 2 | 2.5 |
| Washington | 4 | 2 | 3.0 |
| Wayne | 1 | 3 | 2.0 |
| Webster | 1 | 2 | 1.5 |
| Worth | 1 | 1 | 1.0 |
| Wright | 2 | 3 | 2.5 |

(1 is low relative impact potential, 4 is high relative impact potential)

| County | Industry | Mining | Average Potential Impact Score |
|---|---|---|---|
| Maries | 2 | 1 | 1.5 |
| Mercer | 2 | 1 | 1.5 |
| Miller | 1 | 2 | 1.5 |
| Monroe | 1 | 2 | 1.5 |
| Ozark | 1 | 2 | 1.5 |
| Perry | 1 | 2 | 1.5 |
| Pulaski | 1 | 2 | 1.5 |
| Ray | 1 | 2 | 1.5 |
| Shelby | 1 | 2 | 1.5 |
| Stone | 1 | 2 | 1.5 |
| Webster | 1 | 2 | 1.5 |
| Atchison | 1 | 1 | 1 |
| Barton | 1 | 1 | 1 |
| Carter | 1 | 1 | 1 |
| Chariton | 1 | 1 | 1 |
| Clark | 1 | 1 | 1 |
| Clinton | 1 | 1 | 1 |
| Dade | 1 | 1 | 1 |
| De Kalb | 1 | 1 | 1 |
| Dunklin | 1 | 1 | 1 |
| Grundy | 1 | 1 | 1 |
| Hickory | 1 | 1 | 1 |
| Lewis | 1 | 1 | 1 |
| Linn | 1 | 1 | 1 |
| Livingston | 1 | 1 | 1 |
| Madison | 1 | 1 | 1 |
| Mississippi | 1 | 1 | 1 |
| Nodaway | 1 | 1 | 1 |
| Oregon | 1 | 1 | 1 |
| Pemiscot | 1 | 1 | 1 |
| Putnam | 1 | 1 | 1 |
| Schuyler | 1 | 1 | 1 |
| Scotland | 1 | 1 | 1 |
| St. Clair | 1 | 1 | 1 |
| Vernon | 1 | 1 | 1 |
| Worth | 1 | 1 | 1 |

**Table B13. Relative Potential for Drought Impact to Tourism by County**

| County | Tourism Expenditures | Tourism Employment | Tourism State Sales Tax | State Park Visitors | State Park Expenditures | Average Potential Impact Score |
|---|---|---|---|---|---|---|
| **Adair** | 3 | 4 | 3 | 4 | 3 | 3.4 |
| **Andrew** | 2 | 2 | 2 | 1 | 1 | 1.6 |
| **Atchison** | 2 | 1 | 2 | 1 | 1 | 1.4 |
| **Audrain** | 3 | 3 | 3 | 1 | 1 | 2.2 |
| **Barry** | 3 | 3 | 3 | 4 | 4 | 3.4 |
| **Barton** | 2 | 3 | 2 | 1 | 1 | 1.8 |
| **Bates** | 2 | 2 | 2 | 1 | 1 | 1.6 |
| **Benton** | 3 | 2 | 3 | 2 | 2 | 2.4 |
| **Bollinger** | 1 | 1 | 1 | 1 | 1 | 1.0 |
| **Boone** | 4 | 4 | 4 | 3 | 3 | 3.6 |
| **Buchanan** | 4 | 4 | 4 | 2 | 2 | 3.2 |
| **Butler** | 4 | 4 | 4 | 1 | 1 | 2.8 |
| **Caldwell** | 1 | 1 | 1 | 1 | 1 | 1.0 |
| **Callaway** | 3 | 4 | 3 | 1 | 1 | 2.4 |
| **Camden** | 4 | 4 | 4 | 4 | 4 | 4.0 |
| **Cape Girardeau** | 4 | 4 | 4 | 3 | 3 | 3.6 |
| **Carroll** | 1 | 2 | 1 | 1 | 1 | 1.2 |
| **Carter** | 2 | 2 | 2 | 1 | 1 | 1.6 |
| **Cass** | 4 | 4 | 4 | 1 | 1 | 2.8 |
| **Cedar** | 2 | 2 | 2 | 3 | 3 | 2.4 |
| **Chariton** | 1 | 1 | 1 | 1 | 1 | 1.0 |
| **Christian** | 4 | 4 | 4 | 1 | 1 | 2.8 |
| **Clark** | 1 | 1 | 1 | 2 | 2 | 1.4 |
| **Clay** | 4 | 4 | 4 | 3 | 4 | 3.8 |
| **Clinton** | 2 | 2 | 2 | 2 | 2 | 2.0 |
| **Cole** | 4 | 4 | 4 | 3 | 4 | 3.8 |
| **Cooper** | 3 | 3 | 3 | 1 | 1 | 2.2 |
| **Crawford** | 3 | 3 | 3 | 3 | 3 | 3.0 |
| **Dade** | 1 | 1 | 1 | 1 | 1 | 1.0 |
| **Dallas** | 2 | 2 | 2 | 1 | 1 | 1.6 |
| **Daviess** | 1 | 1 | 1 | 1 | 1 | 1.0 |
| **Dekalb** | 3 | 2 | 3 | 1 | 1 | 2.0 |
| **Dent** | 2 | 2 | 2 | 4 | 4 | 2.8 |
| **Douglas** | 2 | 2 | 2 | 1 | 1 | 1.6 |
| **Dunklin** | 3 | 3 | 3 | 1 | 1 | 2.2 |
| **Franklin** | 4 | 4 | 4 | 4 | 4 | 4.0 |
| **Gasconade** | 3 | 3 | 3 | 1 | 1 | 2.2 |
| **Gentry** | 1 | 1 | 1 | 1 | 1 | 1.0 |
| **Greene** | 4 | 4 | 4 | 1 | 1 | 2.8 |

| County | Tourism Expenditures | Tourism Employment | Tourism State Sales Tax | State Park Visitors | State Park Expenditures | Average Potential Impact Score |
|---|---|---|---|---|---|---|
| Grundy | 2 | 2 | 2 | 2 | 2 | 2.0 |
| Harrison | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Henry | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Hickory | 1 | 1 | 1 | 3 | 3 | 1.8 |
| Holt | 1 | 1 | 1 | 2 | 2 | 1.4 |
| Howard | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Howell | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Iron | 1 | 1 | 1 | 4 | 4 | 2.2 |
| Jackson | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Jasper | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Jefferson | 4 | 4 | 4 | 4 | 4 | 4.0 |
| Johnson | 4 | 4 | 4 | 3 | 3 | 3.6 |
| Knox | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Laclede | 4 | 3 | 4 | 4 | 4 | 3.8 |
| Lafayette | 3 | 3 | 3 | 2 | 3 | 2.8 |
| Lawrence | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Lewis | 1 | 1 | 1 | 2 | 2 | 1.4 |
| Lincoln | 3 | 3 | 3 | 4 | 4 | 3.4 |
| Linn | 2 | 2 | 2 | 2 | 2 | 2.0 |
| Livingston | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Macon | 3 | 3 | 3 | 4 | 3 | 3.2 |
| Madison | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Maries | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Marion | 4 | 4 | 4 | 1 | 1 | 2.8 |
| McDonald | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Mercer | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Miller | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Mississippi | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Moniteau | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Monroe | 1 | 1 | 1 | 3 | 3 | 1.8 |
| Montgomery | 2 | 2 | 2 | 2 | 2 | 2.0 |
| Morgan | 3 | 3 | 3 | 1 | 1 | 2.2 |
| New Madrid | 3 | 2 | 3 | 1 | 1 | 2.0 |
| Newton | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Nodaway | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Oregon | 1 | 1 | 1 | 2 | 1 | 1.2 |
| Osage | 1 | 2 | 1 | 3 | 3 | 2.0 |
| Ozark | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Pemiscot | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Perry | 3 | 3 | 3 | 1 | 1 | 2.2 |

| County | Tourism Expenditures | Tourism Employment | Tourism State Sales Tax | State Park Visitors | State Park Expenditures | Average Potential Impact Score |
|---|---|---|---|---|---|---|
| Pettis | 4 | 4 | 4 | 1 | 2 | 3.0 |
| Phelps | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Pike | 2 | 3 | 2 | 1 | 1 | 1.8 |
| Platte | 4 | 4 | 4 | 2 | 2 | 3.2 |
| Polk | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Pulaski | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Putnam | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Ralls | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Randolph | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Ray | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Reynolds | 1 | 1 | 1 | 3 | 3 | 1.8 |
| Ripley | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Saline | 3 | 3 | 3 | 2 | 2 | 2.6 |
| Schuyler | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Scotland | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Scott | 4 | 3 | 4 | 1 | 1 | 2.6 |
| Shannon | 1 | 1 | 1 | 3 | 2 | 1.6 |
| Shelby | 1 | 1 | 1 | 1 | 1 | 1.0 |
| St Charles | 4 | 4 | 4 | 3 | 3 | 3.6 |
| St Clair | 1 | 1 | 1 | 1 | 1 | 1.0 |
| St Francois | 4 | 4 | 4 | 4 | 4 | 4.0 |
| St Louis | 4 | 4 | 4 | 4 | 4 | 4.0 |
| Ste Genevieve | 2 | 3 | 2 | 2 | 2 | 2.2 |
| Stoddard | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Stone | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Sullivan | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Taney | 4 | 4 | 4 | 4 | 4 | 4.0 |
| Texas | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Vernon | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Warren | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Washington | 2 | 2 | 2 | 3 | 3 | 2.4 |
| Wayne | 2 | 2 | 2 | 4 | 4 | 2.8 |
| Webster | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Worth | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Wright | 2 | 2 | 2 | 1 | 1 | 1.6 |

Based on 10-year averages.

**Table B14. Counties Ranked by Relative Potential for Drought Impact to Tourism**

| County | Tourism Expenditures | Tourism Employment | Tourism State Sales Tax | State Park Visitors | State Park Expenditures | Average Potential Impact Score |
|---|---|---|---|---|---|---|
| Camden | 4 | 4 | 4 | 4 | 4 | 4.0 |
| Franklin | 4 | 4 | 4 | 4 | 4 | 4.0 |
| Jefferson | 4 | 4 | 4 | 4 | 4 | 4.0 |
| St Francois | 4 | 4 | 4 | 4 | 4 | 4.0 |
| St Louis | 4 | 4 | 4 | 4 | 4 | 4.0 |
| Taney | 4 | 4 | 4 | 4 | 4 | 4.0 |
| Clay | 4 | 4 | 4 | 3 | 4 | 3.8 |
| Cole | 4 | 4 | 4 | 3 | 4 | 3.8 |
| Laclede | 4 | 3 | 4 | 4 | 4 | 3.8 |
| Boone | 4 | 4 | 4 | 3 | 3 | 3.6 |
| Cape Girardeau | 4 | 4 | 4 | 3 | 3 | 3.6 |
| Johnson | 4 | 4 | 4 | 3 | 3 | 3.6 |
| St Charles | 4 | 4 | 4 | 3 | 3 | 3.6 |
| Adair | 3 | 4 | 3 | 4 | 3 | 3.4 |
| Barry | 3 | 3 | 3 | 4 | 4 | 3.4 |
| Lincoln | 3 | 3 | 3 | 4 | 4 | 3.4 |
| Buchanan | 4 | 4 | 4 | 2 | 2 | 3.2 |
| Macon | 3 | 3 | 3 | 4 | 3 | 3.2 |
| Platte | 4 | 4 | 4 | 2 | 2 | 3.2 |
| Crawford | 3 | 3 | 3 | 3 | 3 | 3.0 |
| Pettis | 4 | 4 | 4 | 1 | 2 | 3.0 |
| Butler | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Cass | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Christian | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Dent | 2 | 2 | 2 | 4 | 4 | 2.8 |
| Greene | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Howell | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Jackson | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Jasper | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Lafayette | 3 | 3 | 3 | 2 | 3 | 2.8 |
| Marion | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Newton | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Phelps | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Pulaski | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Stone | 4 | 4 | 4 | 1 | 1 | 2.8 |
| Wayne | 2 | 2 | 2 | 4 | 4 | 2.8 |
| Saline | 3 | 3 | 3 | 2 | 2 | 2.6 |
| Scott | 4 | 3 | 4 | 1 | 1 | 2.6 |
| Benton | 3 | 2 | 3 | 2 | 2 | 2.4 |

| County | Tourism Expenditures | Tourism Employment | Tourism State Sales Tax | State Park Visitors | State Park Expenditures | Average Potential Impact Score |
|---|---|---|---|---|---|---|
| Callaway | 3 | 4 | 3 | 1 | 1 | 2.4 |
| Cedar | 2 | 2 | 2 | 3 | 3 | 2.4 |
| Washington | 2 | 2 | 2 | 3 | 3 | 2.4 |
| Audrain | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Cooper | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Dunklin | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Gasconade | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Henry | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Iron | 1 | 1 | 1 | 4 | 4 | 2.2 |
| Lawrence | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Livingston | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Miller | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Morgan | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Nodaway | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Perry | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Polk | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Randolph | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Ste Genevieve | 2 | 3 | 2 | 2 | 2 | 2.2 |
| Stoddard | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Vernon | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Warren | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Webster | 3 | 3 | 3 | 1 | 1 | 2.2 |
| Clinton | 2 | 2 | 2 | 2 | 2 | 2.0 |
| Dekalb | 3 | 2 | 3 | 1 | 1 | 2.0 |
| Grundy | 2 | 2 | 2 | 2 | 2 | 2.0 |
| Linn | 2 | 2 | 2 | 2 | 2 | 2.0 |
| Montgomery | 2 | 2 | 2 | 2 | 2 | 2.0 |
| New Madrid | 3 | 2 | 3 | 1 | 1 | 2.0 |
| Osage | 1 | 2 | 1 | 3 | 3 | 2.0 |
| Barton | 2 | 3 | 2 | 1 | 1 | 1.8 |
| Hickory | 1 | 1 | 1 | 3 | 3 | 1.8 |
| Monroe | 1 | 1 | 1 | 3 | 3 | 1.8 |
| Pike | 2 | 3 | 2 | 1 | 1 | 1.8 |
| Reynolds | 1 | 1 | 1 | 3 | 3 | 1.8 |
| Andrew | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Bates | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Carter | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Dallas | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Douglas | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Harrison | 2 | 2 | 2 | 1 | 1 | 1.6 |

| County | Tourism Expenditures | Tourism Employment | Tourism State Sales Tax | State Park Visitors | State Park Expenditures | Average Potential Impact Score |
|---|---|---|---|---|---|---|
| Madison | 2 | 2 | 2 | 1 | 1 | 1.6 |
| McDonald | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Mississippi | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Moniteau | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Ozark | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Pemiscot | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Ray | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Ripley | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Shannon | 1 | 1 | 1 | 3 | 2 | 1.6 |
| Texas | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Wright | 2 | 2 | 2 | 1 | 1 | 1.6 |
| Atchison | 2 | 1 | 2 | 1 | 1 | 1.4 |
| Clark | 1 | 1 | 1 | 2 | 2 | 1.4 |
| Holt | 1 | 1 | 1 | 2 | 2 | 1.4 |
| Lewis | 1 | 1 | 1 | 2 | 2 | 1.4 |
| Carroll | 1 | 2 | 1 | 1 | 1 | 1.2 |
| Oregon | 1 | 1 | 1 | 2 | 1 | 1.2 |
| Bollinger | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Caldwell | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Chariton | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Dade | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Daviess | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Gentry | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Howard | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Knox | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Maries | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Mercer | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Putnam | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Ralls | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Schuyler | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Scotland | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Shelby | 1 | 1 | 1 | 1 | 1 | 1.0 |
| St Clair | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Sullivan | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Worth | 1 | 1 | 1 | 1 | 1 | 1.0 |

Based on 10-year averages.

**Table B15. Overall Relative Potential for Drought Impact by County**

| County | Agriculture | Municipal Water Supply | Industry | Tourism | Average |
|---|---|---|---|---|---|
| Adair | 3.3 | 3.0 | 2.0 | 3.4 | 2.9 |
| Andrew | 1.7 | 2.5 | 2.5 | 1.6 | 2.1 |
| Atchison | 2.0 | 1.0 | 1.0 | 1.4 | 1.4 |
| Audrain | 3.7 | 3.0 | 2.0 | 2.2 | 2.7 |
| Barry | 3.3 | 3.5 | 4.0 | 3.4 | 3.6 |
| Barton | 4.0 | 2.0 | 1.0 | 1.8 | 2.2 |
| Bates | 3.3 | 2.5 | 1.5 | 1.6 | 2.2 |
| Benton | 3.0 | 1.0 | 1.5 | 2.4 | 2.0 |
| Bollinger | 2.0 | 1.0 | 2.0 | 1.0 | 1.5 |
| Boone | 3.0 | 4.0 | 3.0 | 3.6 | 3.4 |
| Buchanan | 1.7 | 4.0 | 2.5 | 3.2 | 2.8 |
| Butler | 1.3 | 3.5 | 2.0 | 2.8 | 2.4 |
| Caldwell | 2.0 | 1.0 | 1.5 | 1.0 | 1.4 |
| Callaway | 3.3 | 4.0 | 3.5 | 2.4 | 3.3 |
| Camden | 2.0 | 4.0 | 2.5 | 4.0 | 3.1 |
| Cape Girardeau | 2.7 | 4.0 | 4.0 | 3.6 | 3.6 |
| Carroll | 2.7 | 2.0 | 2.0 | 1.2 | 2.0 |
| Carter | 1.0 | 1.0 | 1.0 | 1.6 | 1.2 |
| Cass | 3.7 | 4.0 | 2.5 | 2.8 | 3.2 |
| Cedar | 2.3 | 2.0 | 1.5 | 2.4 | 2.1 |
| Chariton | 2.7 | 1.0 | 1.0 | 1.0 | 1.4 |
| Christian | 2.0 | 4.0 | 2.5 | 2.8 | 2.8 |
| Clark | 2.3 | 2.0 | 1.0 | 1.4 | 1.7 |
| Clay | 2.0 | 4.0 | 4.0 | 3.8 | 3.5 |
| Clinton | 2.7 | 3.0 | 1.0 | 2.0 | 2.2 |
| Cole | 3.3 | 4.0 | 2.0 | 3.8 | 3.3 |
| Cooper | 3.7 | 3.0 | 1.5 | 2.2 | 2.6 |
| Crawford | 2.0 | 2.0 | 3.0 | 3.0 | 2.5 |
| Dade | 3.0 | 1.0 | 1.0 | 1.0 | 1.5 |
| Dallas | 2.7 | 1.0 | 1.5 | 1.6 | 1.7 |
| Daviess | 4.0 | 2.0 | 2.0 | 1.0 | 2.3 |
| Dekalb | 2.3 | 3.0 | 1.0 | 2.0 | 2.1 |
| Dent | 2.0 | 2.0 | 1.5 | 2.8 | 2.1 |
| Douglas | 2.0 | 1.0 | 2.0 | 1.6 | 1.7 |
| Dunklin | 1.7 | 3.5 | 1.0 | 2.2 | 2.1 |
| Franklin | 3.3 | 4.0 | 3.0 | 4.0 | 3.6 |
| Gasconade | 2.0 | 2.0 | 2.0 | 2.2 | 2.1 |
| Gentry | 2.3 | 1.5 | 1.5 | 1.0 | 1.6 |
| Greene | 3.0 | 4.0 | 3.5 | 2.8 | 3.3 |
| Grundy | 2.3 | 2.5 | 1.0 | 2.0 | 2.0 |
| Harrison | 3.0 | 2.0 | 2.0 | 1.6 | 2.2 |
| Henry | 3.3 | 3.0 | 2.0 | 2.2 | 2.6 |
| Hickory | 1.7 | 1.0 | 1.0 | 1.8 | 1.4 |
| Holt | 1.7 | 1.0 | 1.5 | 1.4 | 1.4 |
| Howard | 2.7 | 2.0 | 1.5 | 1.0 | 1.8 |
| Howell | 2.7 | 3.0 | 2.0 | 2.8 | 2.6 |
| Iron | 1.0 | 1.0 | 3.0 | 2.2 | 1.8 |

| County | Agriculture | Municipal Water Supply | Industry | Tourism | Average |
|---|---|---|---|---|---|
| Jackson | 2.0 | 4.0 | 4.0 | 2.8 | 3.2 |
| Jasper | 3.7 | 4.0 | 4.0 | 2.8 | 3.6 |
| Jefferson | 2.0 | 4.0 | 3.5 | 4.0 | 3.4 |
| Johnson | 2.7 | 4.0 | 2.5 | 3.6 | 3.2 |
| Knox | 3.7 | 1.0 | 1.5 | 1.0 | 1.8 |
| Laclede | 2.7 | 4.0 | 1.5 | 3.8 | 3.0 |
| Lafayette | 3.0 | 4.0 | 1.5 | 2.8 | 2.8 |
| Lawrence | 3.7 | 3.0 | 1.5 | 2.2 | 2.6 |
| Lewis | 2.3 | 1.0 | 1.0 | 1.4 | 1.4 |
| Lincoln | 2.3 | 3.5 | 3.0 | 3.4 | 3.1 |
| Linn | 2.7 | 2.0 | 1.0 | 2.0 | 1.9 |
| Livingston | 3.0 | 3.0 | 1.0 | 2.2 | 2.3 |
| Macon | 3.3 | 3.0 | 2.0 | 3.2 | 2.9 |
| Madison | 1.0 | 2.0 | 1.0 | 1.6 | 1.4 |
| Maries | 2.3 | 1.0 | 1.5 | 1.0 | 1.5 |
| Marion | 2.7 | 3.5 | 3.0 | 2.8 | 3.0 |
| McDonald | 2.7 | 2.5 | 3.0 | 1.6 | 2.4 |
| Mercer | 1.7 | 1.0 | 1.5 | 1.0 | 1.3 |
| Miller | 3.0 | 2.0 | 1.5 | 2.2 | 2.2 |
| Mississippi | 1.7 | 3.0 | 1.0 | 1.6 | 1.8 |
| Moniteau | 3.3 | 2.0 | 2.0 | 1.6 | 2.2 |
| Monroe | 3.7 | 2.0 | 1.5 | 1.8 | 2.2 |
| Montgomery | 2.7 | 1.5 | 2.5 | 2.0 | 2.2 |
| Morgan | 3.3 | 2.0 | 2.5 | 2.2 | 2.5 |
| New Madrid | 1.7 | 2.5 | 2.5 | 2.0 | 2.2 |
| Newton | 3.3 | 3.5 | 2.5 | 2.8 | 3.0 |
| Nodaway | 3.3 | 3.0 | 1.0 | 2.2 | 2.4 |
| Oregon | 2.0 | 1.5 | 1.0 | 1.2 | 1.4 |
| Osage | 3.3 | 1.0 | 3.0 | 2.0 | 2.3 |
| Ozark | 2.0 | 1.0 | 1.5 | 1.6 | 1.5 |
| Pemiscot | 2.0 | 3.0 | 1.0 | 1.6 | 1.9 |
| Perry | 2.7 | 2.0 | 1.5 | 2.2 | 2.1 |
| Pettis | 4.0 | 4.0 | 3.5 | 3.0 | 3.6 |
| Phelps | 1.7 | 3.5 | 2.5 | 2.8 | 2.6 |
| Pike | 3.7 | 2.5 | 3.0 | 1.8 | 2.7 |
| Platte | 1.3 | 4.0 | 2.5 | 3.2 | 2.8 |
| Polk | 3.3 | 2.5 | 2.0 | 2.2 | 2.5 |
| Pulaski | 1.7 | 4.0 | 1.5 | 2.8 | 2.5 |
| Putnam | 2.3 | 1.0 | 1.0 | 1.0 | 1.3 |
| Ralls | 2.0 | 2.0 | 3.0 | 1.0 | 2.0 |
| Randolph | 2.3 | 3.0 | 2.0 | 2.2 | 2.4 |
| Ray | 2.7 | 3.0 | 1.5 | 1.6 | 2.2 |
| Reynolds | 1.3 | 1.0 | 2.5 | 1.8 | 1.7 |
| Ripley | 1.3 | 2.0 | 2.0 | 1.6 | 1.7 |
| Saint Charles | 2.3 | 4.0 | 3.5 | 3.6 | 3.4 |
| Saint Clair | 2.3 | 1.0 | 1.0 | 1.0 | 1.3 |
| Saint Francois | 1.7 | 4.0 | 2.5 | 4.0 | 3.0 |
| Saint Louis | 1.0 | 4.0 | 2.5 | 4.0 | 2.9 |

| County | Agriculture | Municipal Water Supply | Industry | Tourism | Average |
|---|---|---|---|---|---|
| **Sainte Genevieve** | 1.7 | 2.0 | 4.0 | 2.2 | 2.5 |
| **Saline** | 3.3 | 3.0 | 2.5 | 2.6 | 2.9 |
| **Schuyler** | 1.7 | 1.0 | 1.0 | 1.0 | 1.2 |
| **Scotland** | 3.0 | 1.0 | 1.0 | 1.0 | 1.5 |
| **Scott** | 3.0 | 4.0 | 2.5 | 2.6 | 3.0 |
| **Shannon** | 1.7 | 1.0 | 2.0 | 1.6 | 1.6 |
| **Shelby** | 2.7 | 1.0 | 1.5 | 1.0 | 1.5 |
| **Stoddard** | 2.7 | 3.0 | 3.5 | 2.2 | 2.8 |
| **Stone** | 2.3 | 2.5 | 1.5 | 2.8 | 2.3 |
| **Sullivan** | 3.0 | 1.5 | 2.0 | 1.0 | 1.9 |
| **Taney** | 1.7 | 4.0 | 4.0 | 4.0 | 3.4 |
| **Texas** | 2.7 | 3.0 | 2.5 | 1.6 | 2.4 |
| **Vernon** | 4.0 | 3.0 | 1.0 | 2.2 | 2.6 |
| **Warren** | 1.7 | 3.0 | 2.5 | 2.2 | 2.3 |
| **Washington** | 1.7 | 1.5 | 3.0 | 2.4 | 2.1 |
| **Wayne** | 1.3 | 1.5 | 2.0 | 2.8 | 1.9 |
| **Webster** | 3.3 | 2.5 | 1.5 | 2.2 | 2.4 |
| **Worth** | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| **Wright** | 3.0 | 2.0 | 2.5 | 1.6 | 2.3 |

**Table B16. Counties Ranked by Overall Relative Potential for Drought Impact**

| County | Agriculture | Municipal Water Supply | Industry | Tourism | Total |
|---|---|---|---|---|---|
| Pettis | 4.0 | 4.0 | 3.5 | 3.0 | 3.6 |
| Jasper | 3.7 | 4.0 | 4.0 | 2.8 | 3.6 |
| Franklin | 3.3 | 4.0 | 3.0 | 4.0 | 3.6 |
| Cape Girardeau | 2.7 | 4.0 | 4.0 | 3.6 | 3.6 |
| Barry | 3.3 | 3.5 | 4.0 | 3.4 | 3.6 |
| Clay | 2.0 | 4.0 | 4.0 | 3.8 | 3.5 |
| Taney | 1.7 | 4.0 | 4.0 | 4.0 | 3.4 |
| Boone | 3.0 | 4.0 | 3.0 | 3.6 | 3.4 |
| Jefferson | 2.0 | 4.0 | 3.5 | 4.0 | 3.4 |
| Saint Charles | 2.3 | 4.0 | 3.5 | 3.6 | 3.4 |
| Greene | 3.0 | 4.0 | 3.5 | 2.8 | 3.3 |
| Callaway | 3.3 | 4.0 | 3.5 | 2.4 | 3.3 |
| Cole | 3.3 | 4.0 | 2.0 | 3.8 | 3.3 |
| Cass | 3.7 | 4.0 | 2.5 | 2.8 | 3.2 |
| Jackson | 2.0 | 4.0 | 4.0 | 2.8 | 3.2 |
| Johnson | 2.7 | 4.0 | 2.5 | 3.6 | 3.2 |
| Camden | 2.0 | 4.0 | 2.5 | 4.0 | 3.1 |
| Lincoln | 2.3 | 3.5 | 3.0 | 3.4 | 3.1 |
| Saint Francois | 1.7 | 4.0 | 2.5 | 4.0 | 3.0 |
| Newton | 3.3 | 3.5 | 2.5 | 2.8 | 3.0 |
| Scott | 3.0 | 4.0 | 2.5 | 2.6 | 3.0 |
| Laclede | 2.7 | 4.0 | 1.5 | 3.8 | 3.0 |
| Marion | 2.7 | 3.5 | 3.0 | 2.8 | 3.0 |
| Adair | 3.3 | 3.0 | 2.0 | 3.4 | 2.9 |
| Macon | 3.3 | 3.0 | 2.0 | 3.2 | 2.9 |
| Saint Louis | 1.0 | 4.0 | 2.5 | 4.0 | 2.9 |
| Saline | 3.3 | 3.0 | 2.5 | 2.6 | 2.9 |
| Buchanan | 1.7 | 4.0 | 2.5 | 3.2 | 2.8 |
| Stoddard | 2.7 | 3.0 | 3.5 | 2.2 | 2.8 |
| Christian | 2.0 | 4.0 | 2.5 | 2.8 | 2.8 |
| Lafayette | 3.0 | 4.0 | 1.5 | 2.8 | 2.8 |
| Platte | 1.3 | 4.0 | 2.5 | 3.2 | 2.8 |
| Pike | 3.7 | 2.5 | 3.0 | 1.8 | 2.7 |
| Audrain | 3.7 | 3.0 | 2.0 | 2.2 | 2.7 |
| Henry | 3.3 | 3.0 | 2.0 | 2.2 | 2.6 |
| Phelps | 1.7 | 3.5 | 2.5 | 2.8 | 2.6 |
| Howell | 2.7 | 3.0 | 2.0 | 2.8 | 2.6 |
| Cooper | 3.7 | 3.0 | 1.5 | 2.2 | 2.6 |
| Lawrence | 3.7 | 3.0 | 1.5 | 2.2 | 2.6 |
| Vernon | 4.0 | 3.0 | 1.0 | 2.2 | 2.6 |
| Morgan | 3.3 | 2.0 | 2.5 | 2.2 | 2.5 |
| Polk | 3.3 | 2.5 | 2.0 | 2.2 | 2.5 |
| Crawford | 2.0 | 2.0 | 3.0 | 3.0 | 2.5 |

| County | Agriculture | Municipal Water Supply | Industry | Tourism | Total |
|---|---|---|---|---|---|
| Pulaski | 1.7 | 4.0 | 1.5 | 2.8 | 2.5 |
| Sainte Genevieve | 1.7 | 2.0 | 4.0 | 2.2 | 2.5 |
| McDonald | 2.7 | 2.5 | 3.0 | 1.6 | 2.4 |
| Texas | 2.7 | 3.0 | 2.5 | 1.6 | 2.4 |
| Butler | 1.3 | 3.5 | 2.0 | 2.8 | 2.4 |
| Nodaway | 3.3 | 3.0 | 1.0 | 2.2 | 2.4 |
| Randolph | 2.3 | 3.0 | 2.0 | 2.2 | 2.4 |
| Webster | 3.3 | 2.5 | 1.5 | 2.2 | 2.4 |
| Warren | 1.7 | 3.0 | 2.5 | 2.2 | 2.3 |
| Osage | 3.3 | 1.0 | 3.0 | 2.0 | 2.3 |
| Livingston | 3.0 | 3.0 | 1.0 | 2.2 | 2.3 |
| Stone | 2.3 | 2.5 | 1.5 | 2.8 | 2.3 |
| Wright | 3.0 | 2.0 | 2.5 | 1.6 | 2.3 |
| Daviess | 4.0 | 2.0 | 2.0 | 1.0 | 2.3 |
| Monroe | 3.7 | 2.0 | 1.5 | 1.8 | 2.2 |
| Bates | 3.3 | 2.5 | 1.5 | 1.6 | 2.2 |
| Moniteau | 3.3 | 2.0 | 2.0 | 1.6 | 2.2 |
| Barton | 4.0 | 2.0 | 1.0 | 1.8 | 2.2 |
| Ray | 2.7 | 3.0 | 1.5 | 1.6 | 2.2 |
| Miller | 3.0 | 2.0 | 1.5 | 2.2 | 2.2 |
| New Madrid | 1.7 | 2.5 | 2.5 | 2.0 | 2.2 |
| Clinton | 2.7 | 3.0 | 1.0 | 2.0 | 2.2 |
| Montgomery | 2.7 | 1.5 | 2.5 | 2.0 | 2.2 |
| Harrison | 3.0 | 2.0 | 2.0 | 1.6 | 2.2 |
| Washington | 1.7 | 1.5 | 3.0 | 2.4 | 2.1 |
| Dunklin | 1.7 | 3.5 | 1.0 | 2.2 | 2.1 |
| Perry | 2.7 | 2.0 | 1.5 | 2.2 | 2.1 |
| Dekalb | 2.3 | 3.0 | 1.0 | 2.0 | 2.1 |
| Dent | 2.0 | 2.0 | 1.5 | 2.8 | 2.1 |
| Andrew | 1.7 | 2.5 | 2.5 | 1.6 | 2.1 |
| Cedar | 2.3 | 2.0 | 1.5 | 2.4 | 2.1 |
| Gasconade | 2.0 | 2.0 | 2.0 | 2.2 | 2.1 |
| Ralls | 2.0 | 2.0 | 3.0 | 1.0 | 2.0 |
| Benton | 3.0 | 1.0 | 1.5 | 2.4 | 2.0 |
| Carroll | 2.7 | 2.0 | 2.0 | 1.2 | 2.0 |
| Grundy | 2.3 | 2.5 | 1.0 | 2.0 | 2.0 |
| Linn | 2.7 | 2.0 | 1.0 | 2.0 | 1.9 |
| Wayne | 1.3 | 1.5 | 2.0 | 2.8 | 1.9 |
| Pemiscot | 2.0 | 3.0 | 1.0 | 1.6 | 1.9 |
| Sullivan | 3.0 | 1.5 | 2.0 | 1.0 | 1.9 |
| Mississippi | 1.7 | 3.0 | 1.0 | 1.6 | 1.8 |
| Iron | 1.0 | 1.0 | 3.0 | 2.2 | 1.8 |
| Howard | 2.7 | 2.0 | 1.5 | 1.0 | 1.8 |
| Knox | 3.7 | 1.0 | 1.5 | 1.0 | 1.8 |

| County | Agriculture | Municipal Water Supply | Industry | Tourism | Total |
|---|---|---|---|---|---|
| Ripley | 1.3 | 2.0 | 2.0 | 1.6 | 1.7 |
| Dallas | 2.7 | 1.0 | 1.5 | 1.6 | 1.7 |
| Clark | 2.3 | 2.0 | 1.0 | 1.4 | 1.7 |
| Reynolds | 1.3 | 1.0 | 2.5 | 1.8 | 1.7 |
| Douglas | 2.0 | 1.0 | 2.0 | 1.6 | 1.7 |
| Gentry | 2.3 | 1.5 | 1.5 | 1.0 | 1.6 |
| Shannon | 1.7 | 1.0 | 2.0 | 1.6 | 1.6 |
| Shelby | 2.7 | 1.0 | 1.5 | 1.0 | 1.5 |
| Ozark | 2.0 | 1.0 | 1.5 | 1.6 | 1.5 |
| Bollinger | 2.0 | 1.0 | 2.0 | 1.0 | 1.5 |
| Dade | 3.0 | 1.0 | 1.0 | 1.0 | 1.5 |
| Scotland | 3.0 | 1.0 | 1.0 | 1.0 | 1.5 |
| Maries | 2.3 | 1.0 | 1.5 | 1.0 | 1.5 |
| Lewis | 2.3 | 1.0 | 1.0 | 1.4 | 1.4 |
| Oregon | 2.0 | 1.5 | 1.0 | 1.2 | 1.4 |
| Chariton | 2.7 | 1.0 | 1.0 | 1.0 | 1.4 |
| Madison | 1.0 | 2.0 | 1.0 | 1.6 | 1.4 |
| Holt | 1.7 | 1.0 | 1.5 | 1.4 | 1.4 |
| Caldwell | 2.0 | 1.0 | 1.5 | 1.0 | 1.4 |
| Hickory | 1.7 | 1.0 | 1.0 | 1.8 | 1.4 |
| Atchison | 2.0 | 1.0 | 1.0 | 1.4 | 1.4 |
| Putnam | 2.3 | 1.0 | 1.0 | 1.0 | 1.3 |
| Saint Clair | 2.3 | 1.0 | 1.0 | 1.0 | 1.3 |
| Mercer | 1.7 | 1.0 | 1.5 | 1.0 | 1.3 |
| Schuyler | 1.7 | 1.0 | 1.0 | 1.0 | 1.2 |
| Carter | 1.0 | 1.0 | 1.0 | 1.6 | 1.2 |
| Worth | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

# Appendix C
# Methodology for PDSI Projections

This appendix provides more information on the analysis performed to project future Palmer Drought Severity Index (PDSI) values across Missouri by climate division.

Global climate model (GCM) projections were downloaded from a widely used U.S. Bureau of Reclamation data portal (available at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/). Only projections from the latest World Climate Research Programme's Coupled Model Intercomparison Project Release 5 (CMIP 5) were used in this analysis; specifically, monthly projections of both air temperature and precipitation through the year 2099. While projections were downloaded and analyzed through year 2099, results in Section 5 of the plan were only reported through year 2070, owing to the increasing uncertainty of projections near the end of the century. A total of 112 GCM projections were utilized, spanning 37 different climate models and a range of standard assumptions about future greenhouse gas emissions. These projections represent the best available science on future climate conditions.

Statistical trend analysis was performed for each of the GCM precipitation projection data sets and each corresponding calculated PDSI trace. Mann-Kendall non-parametric tests, applied within the Excel add-in XLSTAT, were used for the analysis. Statistical significance levels were defined as having a p-value of less than 0.05, which translates to a five percent or less probability of getting a result more extreme by random chance. Analyses were performed for the full 21st century projection period (2000 – 2099) using the monthly timestep projection data.

The range of variability in projected long-term shifts in drought conditions across GCMs is shown by climate division in **Figure C-1** through **Figure C-6**. Note that each point corresponds to a single GCM projection. These results further highlight the non-stationarity in the PDSI projections. The results also indicate a potential for severe to extreme multi-decade drought conditions with a central tendency toward moderate drought conditions by the end of the century and a large range of projection variability. As expected, the variability in the projections increases further out in the future due to uncertainty inherently increasing with additional time.

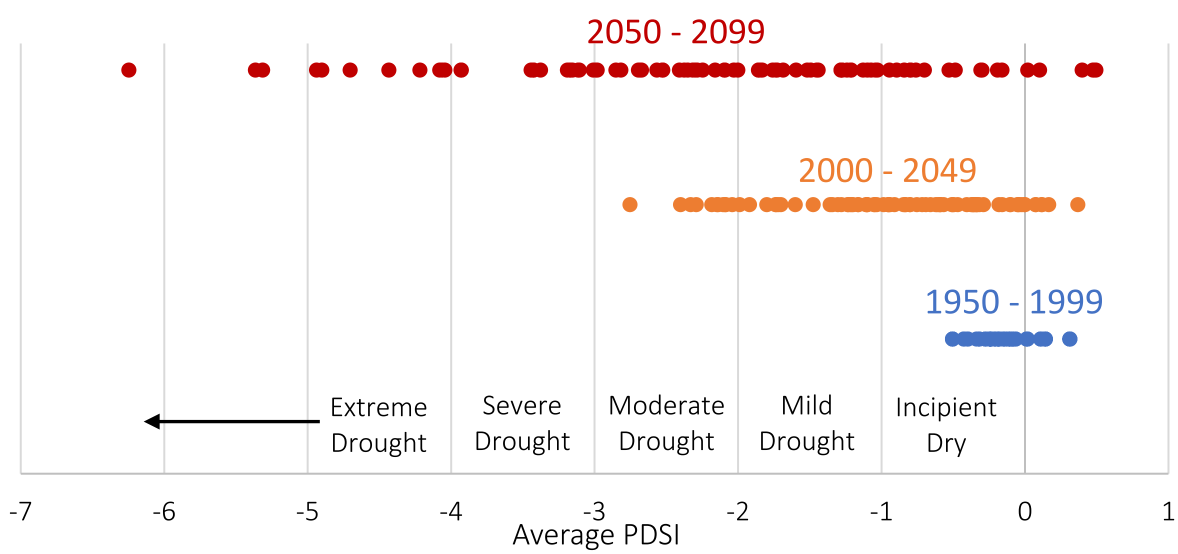



Figure C-1. Projected Average PDSI in 50-Year Intervals – Bootheel

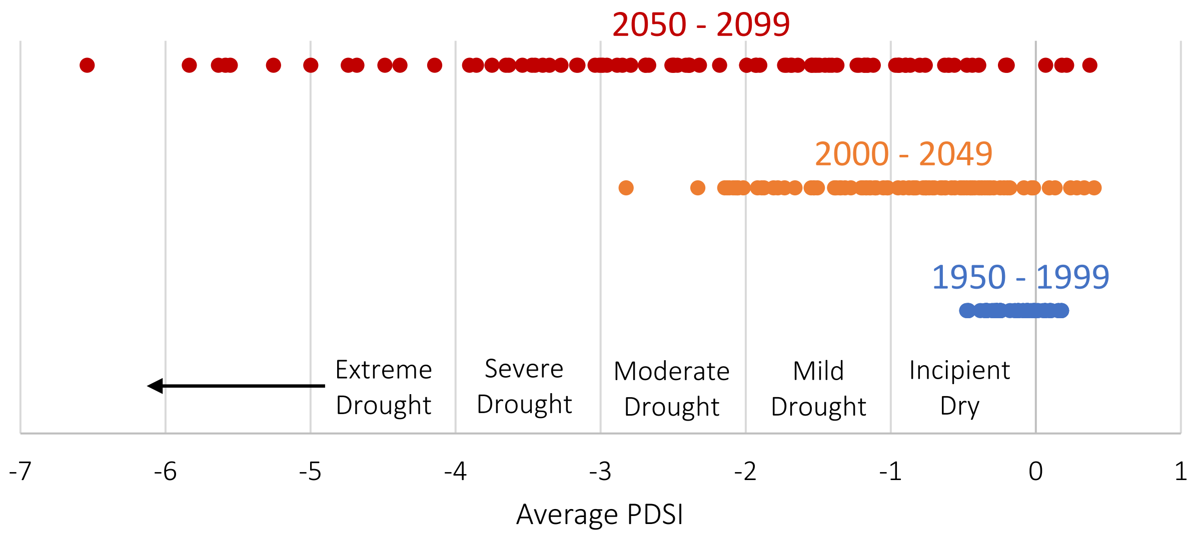



Figure C-2. Projected Average PDSI in 50-Year Intervals – East Ozarks

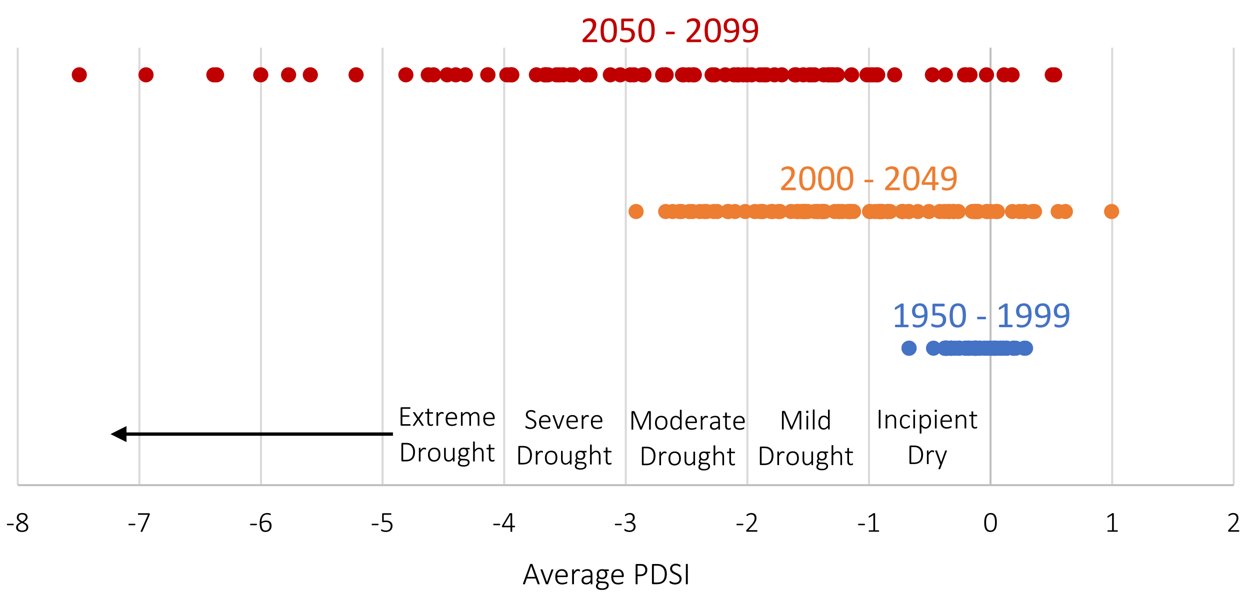



Figure C-3. Projected Average PDSI in 50-Year Intervals – Northeast Prairie

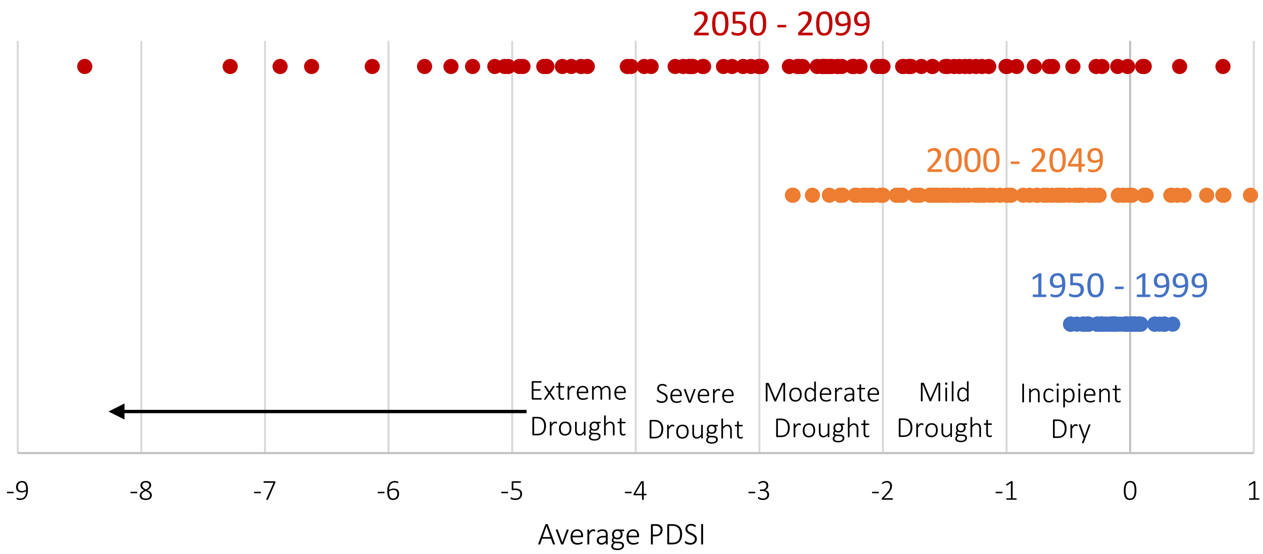



Figure C-4. Projected Average PDSI in 50-Year Intervals – Northwest Prairie

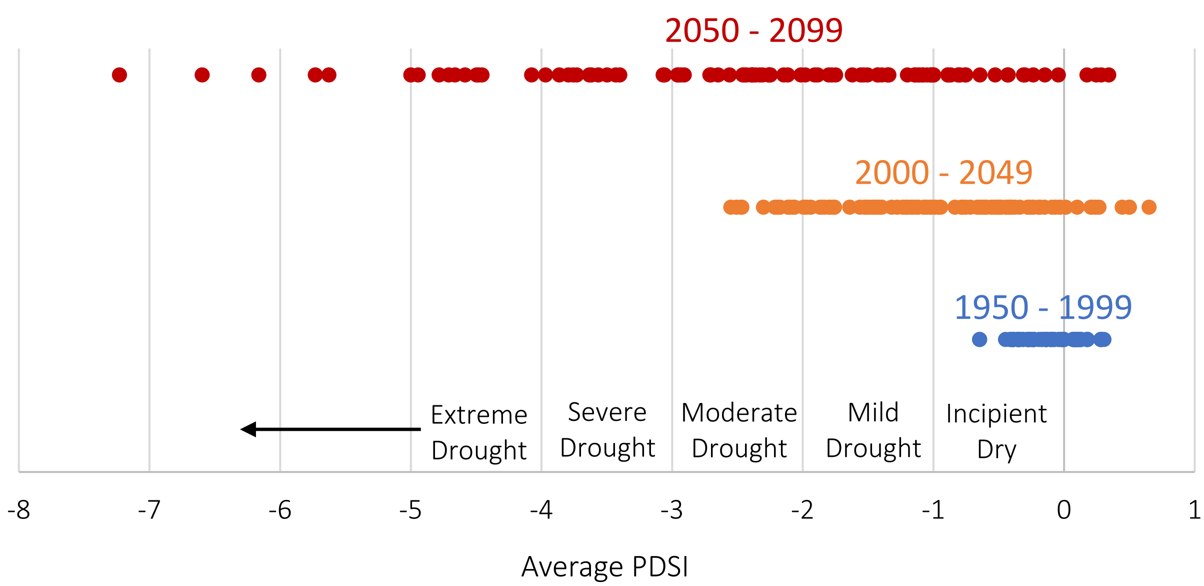



Figure C-5. Projected Average PDSI in 50-Year Intervals – West Central Plains

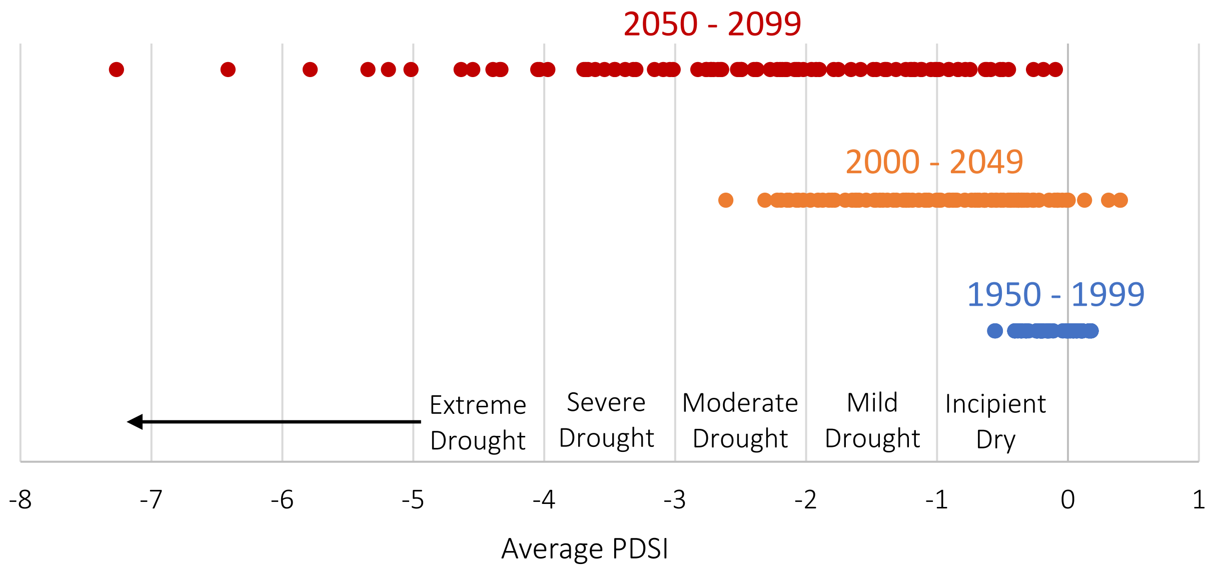



Figure C-6. Projected Average PDSI in 50-Year Intervals – West Ozarks

# Appendix D
# Water Supply Modeling Example

## Overview

During development of the Missouri Drought Mitigation and Response Plan, water supply modeling was performed to demonstrate the value of such modeling in support of supply and drought planning. The City of Moberly was selected as a case study for this work, as shown in **Figure D1**. The city sources its water exclusively from Sugar Creek Reservoir. A previous reservoir yield study (Rouse and Schneider, undated) provided the required information to construct the new model. The city, in Randolph County in the north central part of the state, serves approximately 12,000 people, with an average reservoir withdrawal of 1.3 million gallons per day (MGD).

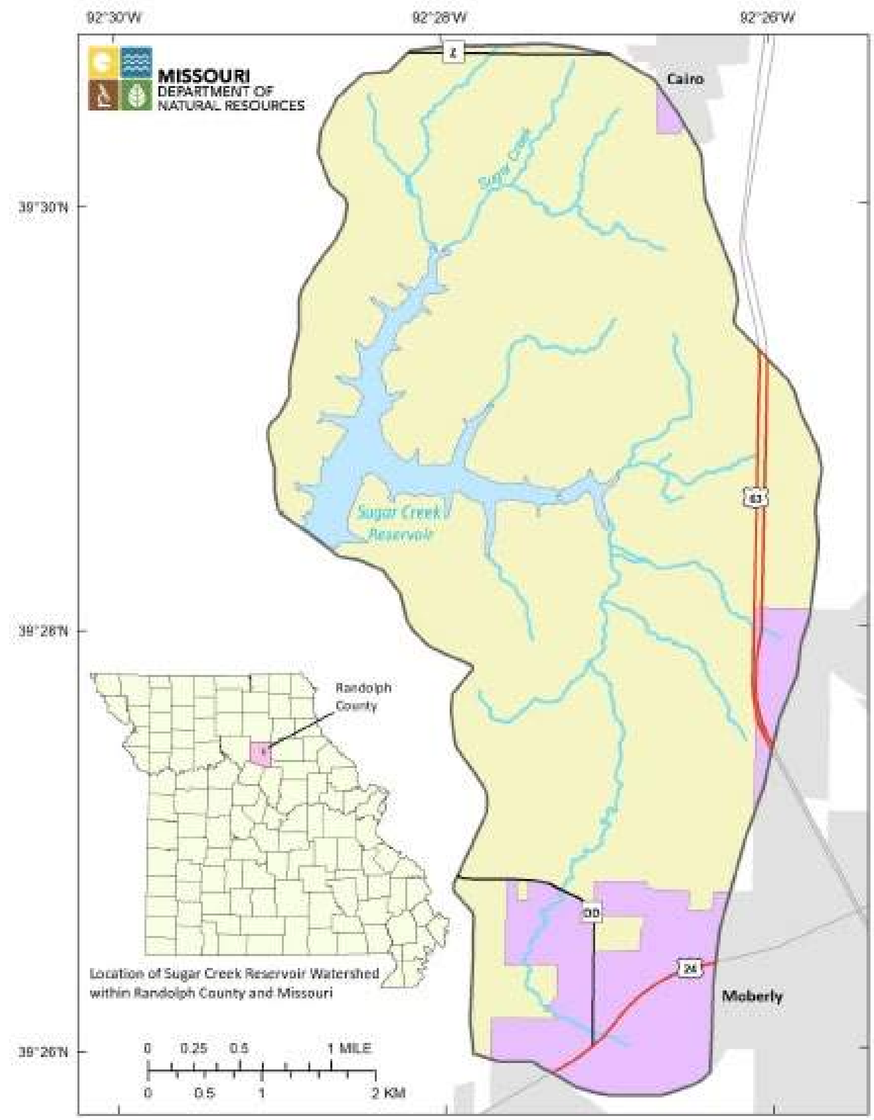



Figure D1. City of Moberly and Sugar Creek Reservoir, MO

## Methods

The model was constructed using CDM Smith's Simplified Water Allocation Model (SWAM) software. SWAM is a generalized, flexible, and dynamic water allocation and reservoir yield modeling platform. A screen shot of the SWAM interface is shown in **Figure D2**. It is well suited for this type of analysis. The model simulates a continuous hydrologic period spanning April 1948 through November 2021. Model calculations are performed on a monthly timestep.

Sugar Creek Reservoir bathymetric and operational details were obtained from the previous yield study. The representation of Sugar Creek Reservoir, in its current state, includes lumped inflows, outflows in the form of evaporative losses, leakage, and City withdrawals, and an inactive pool (below which no withdrawals are possible). Leakage losses were parameterized based on estimates provided in the previous yield study. For this study, leakage was assumed to decrease linearly with decreasing storage volume, from a maximum leakage (1.6 cubic feet per second [cfs] or 720 gallons per minute [gpm]) at full capacity. Reservoir net evaporation rates, as monthly mean values, were estimated from regional (Randolph County) pan evaporation and precipitation data.

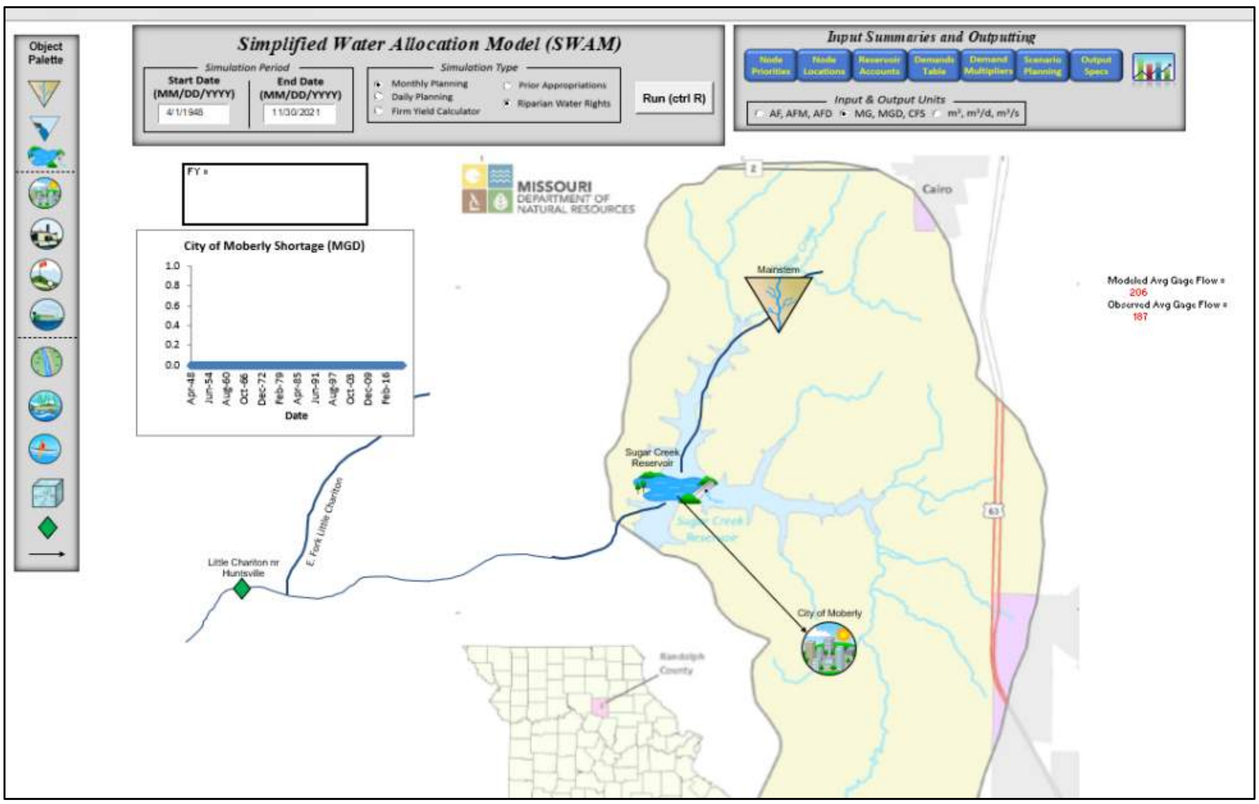



**Figure D2. SWAM modeling platform. Sugar Creek Reservoir and City of Moberly**

Reservoir inflows were estimated using a method consistent with the previous yield study. Flows into the reservoir are ungaged. Therefore, standard ungaged flow estimation techniques were employed to estimate monthly flow totals into the reservoir for the simulated hydrologic period. The United States Geological Survey (USGS) flow gage 06909500 (Moniteau Creek near Fayette, MO) was used as a surrogate gage for this calculation. Moniteau Creek gaged monthly flows were multiplied by the ratio of drainage areas for the reservoir inflow and gage sites, respectively, to calculate approximate monthly flows into the reservoir. Additionally, a data gap in the Moniteau Creek data (c. 1969 – 2001) was filled using the Maintenance of Variance Extension (MOVE.2) statistical technique and a second surrogate flow gage (USGS gage 05506800, Elk Fork Salt River near Madison). The result of this preprocessing exercise was a continuous monthly

timeseries of estimated flows into Sugar Creek Reservoir. These flows served as inputs to the water supply model.

The City of Moberly was parameterized with an average annual demand of 1.3 MGD, distributed seasonally based on software default distribution factors that represent typical monthly variation in water usage. The reservoir was simulated as the sole source of water for the city and reservoir withdrawals were assumed to be continuous, following a repeating monthly pattern, throughout the simulation period. No legal constraints on withdrawals from the reservoir were included.

A downstream USGS flow gage, Little Chariton near Huntsville (USGS 06906300), was included in the model to serve as a useful reference point. The flow at this location in the river is dominated by the East Fork of the Little Chariton, but a portion of the total flow is outflow from Sugar Creek Reservoir. This flow gage was included as simulation point in the model to capture downstream water supply scenario impacts. Model reach flow gain factors were used to capture the portion of flow at this location generated from the watershed not inclusive of the Sugar Creek Reservoir catchment. These flow factors were parameterized through an iterative adjustment process that approximately matched modeled with gaged flows at this location.

The verified model was used to simulate a series of potential future conditions ("scenarios") to provide "proof of concept" predictions. The focus of these simulations was on quantifying relative degree of changes forecast by the model and on identifying system sensitivities. The scenarios simulated here include changes in City water requirements (demands), physical changes to the reservoir, and projected changes in local climate and hydrology. The modeled scenarios are summarized below.

- **Scenario 1:** baseline (current) City demands and reservoir condition + projected mid-century climate change
- **Scenario 2:** doubling of City demands + baseline reservoir and climate conditions
- **Scenario 3**: doubling of demands + reduced reservoir seepage + baseline climate
- **Scenario 4:** doubling of demands + projected climate change + baseline reservoir conditions
- **Scenario 5:** doubling of demands + projected climate change + reservoir enlargement
- **Scenario 6**: doubling of demands + projected climate change + City drought conservation actions + baseline reservoir conditions.

Climate change projections are representative of c. 2060 conditions and based on a previously developed ensemble of global climate model projections that project similar hot and (relatively) dry conditions for the region. In other words, the projections are representative of worst-case, mid-century climate projections for the region, with respect to water supply availability. Climate (temperature and precipitation) projections, downscaled to the study region, were translated into system streamflow and reservoir evaporation changes using external models and analysis. Estimated reservoir inflows were adjusted using a timeseries of adjustment factors developed using macroscale hydrologic modeling and the climate projection ensemble. Evaporation rates were adjusted based on a simple empirical relationship between evaporation and air temperature, developed using local data, and air temperature projections. Further details on the methods used for projecting climate change can be found elsewhere in the Missouri Water Resources Plan 2020 Update (MoDNR 2020).

A demand change factor of two (doubling) was assumed as a projection of potential future water use, intended to identify potential system vulnerabilities and mitigation options. Demands could increase significantly due to, for example, population growth or the addition of new large industrial user.

A reservoir mitigation scenario (Scenario 3) is included to quantify potential increased yield that could be achieved by reducing seepage from the reservoir. For this scenario, a 90 percent reduction in seepage is assumed.

A reservoir enlargement scenario (Scenario 5) is included to demonstrate potential increased yield that could be achieved through an increase in storage capacity. This could be achieved through the enlargement of Sugar Creek reservoir or the addition of new storage to the supply system.

Lastly, city conservation was simulated (Scenario 6) by utilizing SWAM's rule-based conservation options. For this scenario, drought triggers for city conservation were set based on reservoir storage levels as shown in **Table D1**. In SWAM, water demand is reduced according to the percentages shown in the table when each reservoir storage trigger is reached.

**Table D1. Simulated City of Moberly Drought Conservation Rules**

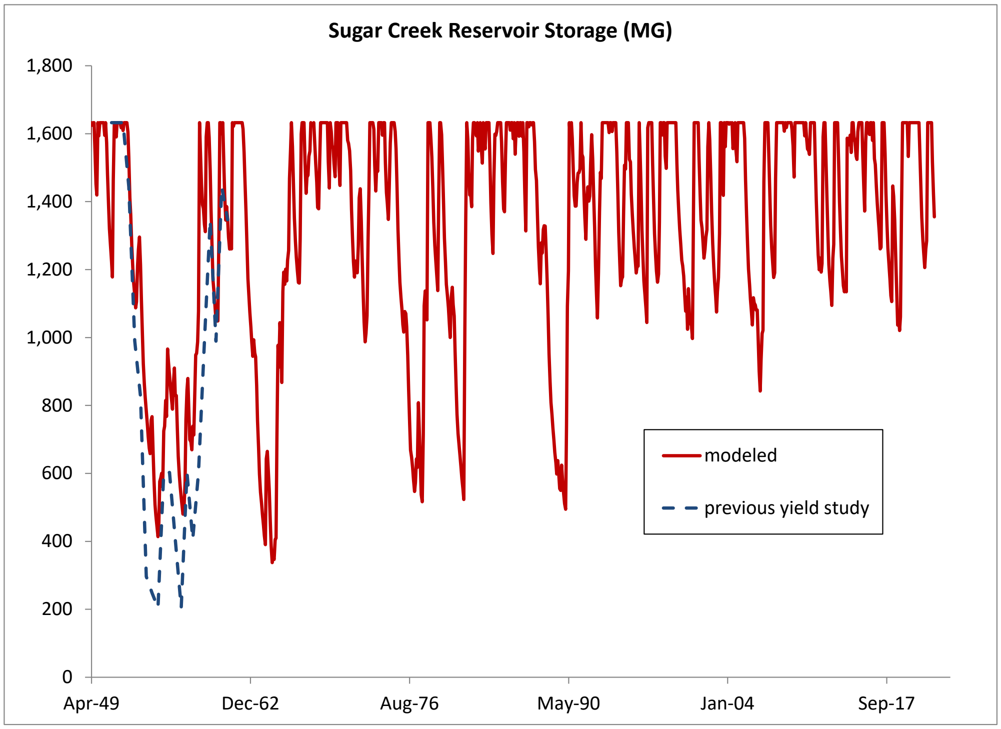
| Reservoir level (% of capacity) | Conservation demand reduction (%) |
|---|---|
| 80% | 15% |
| 60% | 20% |
| 40% | 25% |

## Results

As an initial exercise, the model of the current system (baseline) was assessed against external datasets to verify its ability to adequately replicate current conditions. Simulated reservoir storage levels were compared to published levels from the previous study, for the critical 1950's drought, to verify general congruency between the two models as shown in the top graph of **Figure D3**. The model developed here closely replicates the variability and magnitude of simulated storage, compared to previous results. Minor discrepancies between the two sets of model output are observed, and expected, due to differences in model structure, numerics, and input assumptions. For example, assumed reservoir evaporation rates are slightly different between the two models. This analysis verifies general agreement between the new model and the model developed as part of the previous yield study.

Downstream (Little Chariton) simulated flows were compared to gaged flows at the same location (USGS 06906300). Model reach flow factors were adjusted to achieve an adequate agreement between the range and frequency of modeled and measured flows at this location as shown in the bottom graph of **Figure D3**. These results verify the model's ability to simulate downstream river hydrology.

Scenario simulation results are summarized in Table 3. Example timeseries (reservoir storage and City shortages) are shown in **Figure D4**. Results highlight previously identified vulnerabilities in the city water supply system. Baseline reservoir levels approach the inactive pool during critical drought conditions, indicating a limited current system capacity to support increased demands or future limits on supply availability. Quantified shortages for future scenarios further highlight this vulnerability. The modeling has also revealed additional vulnerability due to climate change, specifically due to increased reservoir evaporative loss resulting from rising temperatures. Lastly, the modeling has identified and quantified, potential mitigation options, including storage augmentation, reservoir seepage repair, and municipal drought conservation plans, that could be implemented to address noted vulnerabilities. More broadly, this work demonstrates the value of water supply systems modeling to support long-term planning.



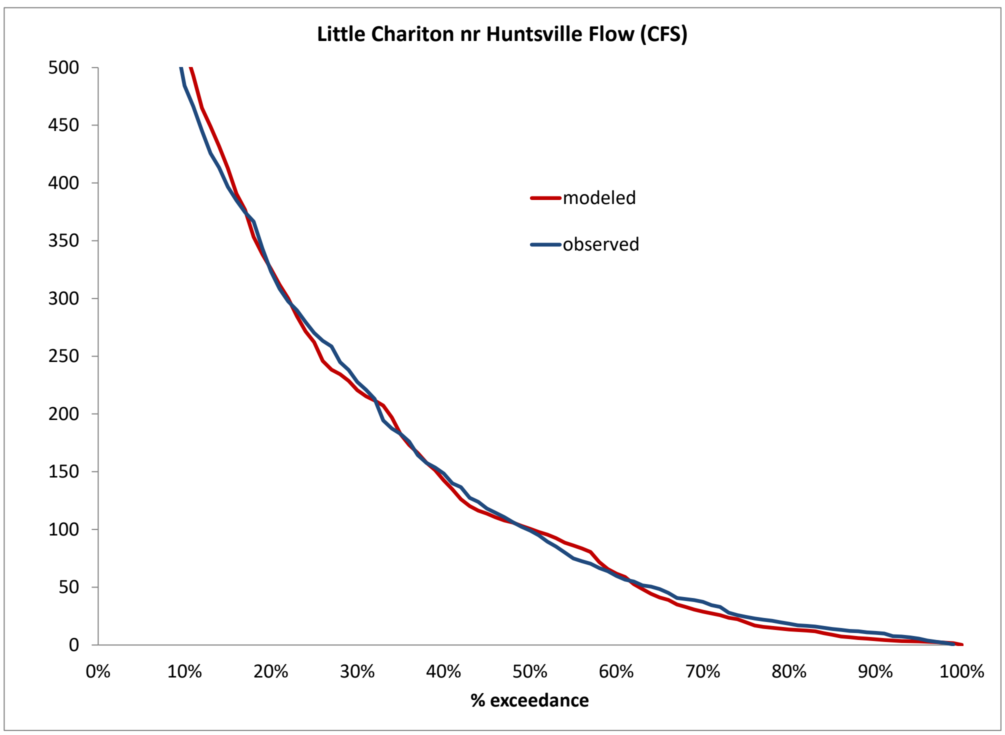
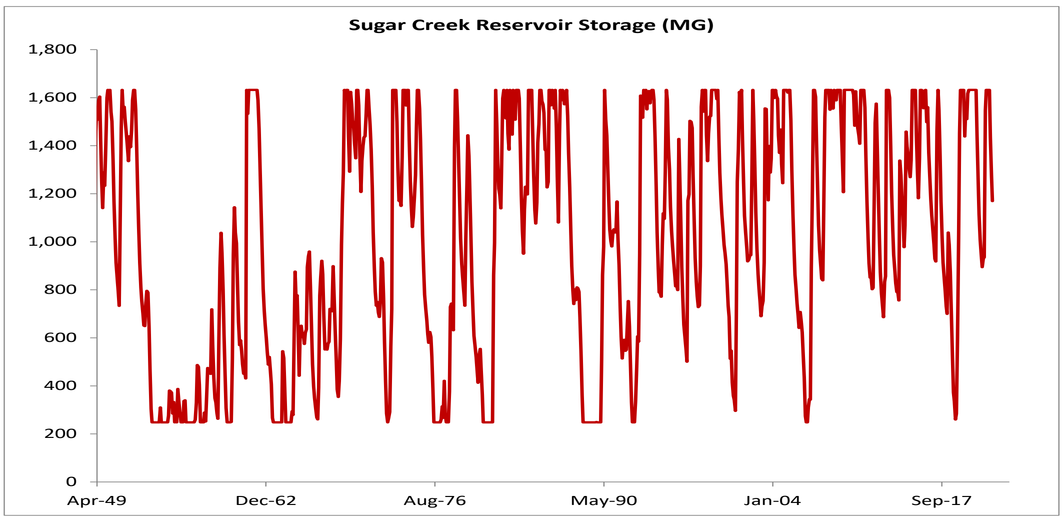




**Figure D3. Model verification results: baseline model. The top graph depicts modeled reservoir storage compared to modeled storage from the previous yield study. The bottom graph depicts the range and frequency of modeled and observed streamflow.**

**Table D2. Sugar Creek Reservoir and City of Moberly Water Supply Modeling Results**

| Metric | Baseline | (1) Baseline, Climate Change | (2) Double Demands | (3) Double Demands w/ Reduced Seepage | (4) Double Demands, Climate Change | (5) Double Demands, Climate Change, Res. Enlargement (5,000 MG) | (6) Double Demands, Climate Change, Conservation |
|---|---|---|---|---|---|---|---|
| Frequency of shortage (%) | 0% | 0% | 9% | 6% | 11% | 0% | 7% |
| Avg. downstream flow (cfs) | 206 | 206 | 205 | 204 | 209 | 208 | 206 |
| Avg. reservoir storage (MG) | 1328 | 1273 | 1049 | 1164 | 1011 | 3417 | 1072 |
| Firm Yield (MGY) | 520 | 480 | 520 | 680 | 480 | 970 | 620 |
| Avg. evap. loss (MGY) | 65 | 110 | 57 | 60 | 97 | 265 | 100 |



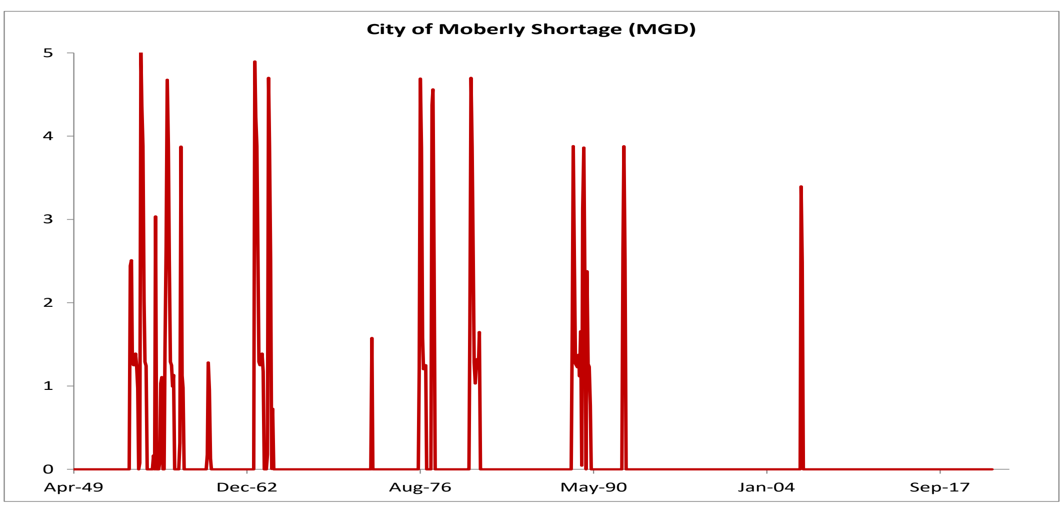




**Figure D4. Example scenario simulation results for Scenario 2 (double city demands with climate change). The top graph depicts modeled reservoir storage. The bottom graph depicts the water supply shortage.**

## References

MoDNR. 2020. *Missouri Water Resources Plan*. Update 2020. Available

Rouse, K. and Schneider, E. *undated*. Firm Yield Assessment: Sugar Creek Lake, Randolph County, Missouri. Missouri Department of Natural Resources Water Resources Center Report (yet to be published).

# Appendix E
# Proposed Drought Response System

The proposed Drought Response System provides for measured responses to worsening effects of drought. It allows for flexibility when assessing and declaring a county, regional, or state–level drought phase. Recommended public notification and response actions are provided for each phase of drought. Each drought declaration phase includes actions in responding to drought and guides both local and statewide mitigation efforts.

## Phases of the Drought Response System

The proposed Drought Response System includes five phases: advisory, incipient, alert, conservation, and emergency. The advisory phase (phase 0) represents the lack of drought conditions. An incipient drought (phase 1) may be declared for a county or region if any of the indices or indicators indicate emergence of incipient drought conditions; however, a signal by one index or indicator alone does not mandate a declaration.

The proposed primary and secondary indices and indicators that should be considered on a weekly basis to determine movement from one drought phase to another are listed in **Table E1**. Index or indicator trigger levels have been established for each phase of the drought response system. Although movement from one drought phase to another may be declared based on any one of the indices or indicators, the five primary indices and indicators are generally intended to be used in concert with each other using a “convergence of evidence” approach. Direct observation of conditions and impacts made by public water providers, farmers, businesses, industry, and other stakeholders within an affected area may also be considered when making drought phase declarations.

The Evaporative Demand Drought Index (EDDI) and QuickDRI indicator, are intended to be used as supplements to the primary indices and indicators. They monitor for rapidly changing drought conditions, including the potential onset of a flash drought. Based on interpretation of the EDDI and QuickDRI, the Missouri Department of Natural Resources (MoDNR) may warn of rapidly changing conditions that suggest an impending change to new drought phase (worsening of drought), or may consider the evidence provided by the secondary indicators as sufficient to make a specific drought phase declaration without delay.

The Climate and Weather Committee (CWC), Drought Assessment Committee (DAC), Drought Executive Committee (DEC), impact teams (ITs), and local water shortage teams maintain specific roles based for each phase of drought. The roles, responsibilities, and major actions taken by the CWC, DAC, DEC, ITs, and local water shortage teams are summarized in Section 6. Specific actions that each entity takes within each phase of the Drought Response System are summarized below.

### Phase 0 – Advisory Phase

MoDNR’s Water Resources Center (WRC), in consultation with the state climatologist, conducts weekly reviews of the drought indices and indicators, and other climate conditions and forecasts. A climate and hydrology report is prepared and distributed to leadership of MoDNR, the Missouri Geological Survey, the MoDNR Division of Environmental Quality, and WRC staff. The advisory phase continues if indices and indicators show no evidence of emerging drought conditions. Based on interpretation of the secondary indices and indicators, MoDNR may warn of rapidly changing conditions that suggest impending movement to the incipient phase for certain counties or regions and potential activation of the CWC.

**Table E1. Drought Response System Phases and Triggers**

| Primary Indices and Indicators | Drought Phase Triggers | | | | |
|---|---|---|---|---|---|
| | **Advisory Phase 0** | **Incipient Phase 1** | **Alert Phase 2** | **Conservation Phase 3** | **Emergency Phase 4** |
| **U.S. Drought Monitor (USDM)**<br>Uses a variety of drought, climatological, hydrological, soil moisture, and other indicators. | No condition | DO (Abnormally Dry) | D1 (Moderate) | D2 (Severe) | D3 and D4 (Extreme to Exceptional) |
| **Standard Precipitation Index (SPI)**<br>Compares observed precipitation over 1- to 24-month periods with long-term averages for the same period. | > -0.50 | -0.50 to -0.99 | -1.00 to -1.49 | -1.50 to -1.99 | ≤2.00 |
| **Palmer Drought Severity Index (PDSI)**<br>Incorporates monthly temperature and precipitation along with water holding capacity of soils. | > -0.50 | -0.50 to -1.49 | -1.50 to -2.99 | -3.00 to -3.99 | ≤ 4.00 |
| **Crop Moisture Index (CMI)**<br>Uses the difference between potential evapotranspiration and moisture to indicate short-term moisture supply for crop producing regions. | > 0.00 | 0.00 to -0.99 | -1.00 to -1.99 | -2.00 to -2.99 | ≤ 3.00 |
| **Streamflow (28-day)**<br>Compares observed streamflow over a 28-day period with long-term averages for the same period. | > 25 percentile | 10 to 25 percentile | 6 to 9 percentile | 2 to 5 percentile | < 2 percentile |
| **Secondary Indices and Indicators** | **Drought Phase Triggers** | | | | |
| | **Advisory Phase 0** | **Incipient Phase 1** | **Alert Phase 2** | **Conservation Phase 3** | **Emergency Phase 4** |
| **Evaporative Demand Drought Index (EDDI)**<br>The EDDI examines how anomalous the atmospheric evaporative demand is for a given location over 1 and 4 weeks. | Normal or below normal evaporative demand (EW0-EW4) | EDO | ED1 | ED2 | ED3 or ED4 |
| **QuickDRI**<br>QuickDRI represents a drought alarm indicator of emerging or rapidly changing drought conditions. | In areas showing an intense signal, this may indicate that a drought phase should be considered, or the existing drought phase changed at that location. | | | | |

### Phase 1 – Incipient Phase

Incipient phase conditions correlate to the USDM D0 category representing abnormally dry conditions. When the USDM and/or other primary indices and indicators signal the emergency of dry conditions, MoDNR declares a phase 1 drought for affected counties or regions, formally activates the CWC, and notifies the MoDNR Department Director that a worsening of conditions may warrant activation of the DAC. Emerging or rapidly changing conditions, as observed using the secondary indices, can also trigger movement into this phase and the potential activation of the DAC at the discretion of the director. Monitoring and consideration of the indices and indicators should accelerate if conditions approach or enter the alert phase.

### Phase 2 – Alert Phase

The alert phase is declared when the CWC recognizes worsening but still moderate drought conditions as reflected by the alert phase indices and indicator triggers. The MoDNR Department Director requests the Governor make a phase 2 drought declaration for the counties or regions of the state experiencing alert phase drought conditions, which correlate to the USDM D1 category representing moderate drought.

The DAC is activated and populated by representatives from key state and federal agencies and supported by input from stakeholders representing impacted counties or regions. ITs may be formed to interact with key stakeholders and assist in data gathering and review. ITs may be asked to conduct analyses and report on conditions in specific counties or regions.

Once the alert phase is declared, the DAC is expected to carry out the following actions in this and subsequent phases:

1. Oversee disseminating information to the public on existing and potential drought conditions and potential future water conservation measures that may be necessary should conditions worsen. Water systems in the affected areas should be notified.

2. Make recommendations related to the proposed state actions, including the activation of ITs to monitor and review potential impacts on the state's agriculture, economy, environment, and natural resources.

3. Augment the climate and hydrology report with a drought status report for the affected counties. The drought status report should summarize both observed and potential impacts, as reported on by ITs and stakeholders within affected counties or regions.

4. Make recommendations to the governor concerning state-level or regional response and recovery.

5. Coordinate with the governor and others, as needed, to develop special drought legislation.

6. Identify resource deficiencies that may aggravate drought effects.

### Phase 3 – Conservation Phase

The conservation phase is declared when the CWC recognizes worsening drought conditions as reflected by the conservation phase indices and indicator triggers, and forecasts indicate an extended period of below-normal precipitation. The MoDNR Department Director requests the governor make a drought declaration for the counties or regions of the state experiencing conservation phase drought conditions, which correlate to the USDM D2 category representing severe drought. Once phase 3 is declared, actions to conserve water are warranted. The DAC empowers the ITs to encourage impacted areas to implement water conservation and take other plan-recommended actions and strategies to reduce demand and conserve supplies.

### Phase 4 – Drought Emergency

The emergency phase is declared when drought conditions enter the USDM D3 (extreme) or D4 (exceptional) categories and forecasts indicate continued below-normal precipitation, suggesting emergency actions are necessary to support essential water uses and protect public health. The MoDNR Department Director may request the governor make a drought declaration for the counties or regions of the state experiencing emergency phase conditions. The governor activates the DEC independently or upon recommendation of the DAC. The Missouri Department of Agriculture may draft an executive order for an agricultural disaster declaration and a health and public safety declaration may be drafted by the Missouri Emergency Management Association.

The DEC is composed of agency heads or their designees and other appropriate state representatives who have authority to commit agency staff and resources to respond to drought emergencies. DEC membership may include members of the DAC who have authority to act on behalf of the agency head in this capacity. The DEC is chaired by the MoDNR Department Director or an appointee named by the governor and meets on a regular basis for the purpose of administering and coordinating drought assistance in Missouri. The DEC is charged with developing short- and long-term recommendations and options for the governor as they relate to all aspects of drought response and management, including public health, safety, and welfare; and social, economic, and environmental concerns. Recommendations and options are based upon data and information provided by the DAC.

# Appendix F
# Water Conservation

The measures listed below are suggestions for efficient water use. They are listed by use type and drought phase. Naturally, all such measures are even more appropriate during worsening drought conditions.

## Indoor Residential Use

### Conservation for Normal (Advisory) Conditions and Incipient Drought Phase

- Replace older toilets with 1.0 gallon per flush toilet or dual flush toilet.
- Install showerhead using 1.5 gallons per minute.
- Replace older clothes washer with washer that meets Consortium for Energy Efficiency (CEE) specifications. CEE specifications apply to both energy use and water use.
- Install faucet aerators on bathroom and kitchen faucets.
- Turn off faucets while brushing teeth, shaving, etc.
- Use clothes washer only when full or adjust water level.
- Use dishwashers only when full or wash dishes by hand (don't let the tap run).
- Do not use the toilet as a trash can.
- Find and fix leaks in toilets, which can leak silently. Place a drop of food coloring in the upper tank and do not flush for 30 minutes. If color appears in the bowl, there is a leak.
- Fix leaks in faucets. Faucets can usually be fixed by replacing washers.
- Learn to read your water meter. Turn off all water-using appliances. If meter is registering use then there is a leak somewhere.
- Conduct an audit of indoor water use.

### Conservation for Drought Alert, Conservation, and Emergency Phases

In addition to the measures listed above:

- Reduce the number of toilet flushes per day.
- Take shorter showers and shallower baths.
- Turn off shower while soaping up.
- Use disposable eating utensils.

- Use non-phosphate detergent and save laundry water for lawns and plants.

## Outdoor Residential Use

### Conservation for Normal (Advisory) Conditions and Incipient Drought Phase

- Water before 10:00 A.M. to limit evaporation, which occurs during the hottest part of the day. Morning is better than evening when the dampness encourages growth of fungus.
- Water only when lawn shows signs of wilt. Grass that springs back when stepped on does not need water.
- Water thoroughly, not frequently; long enough to soak roots. Water slowly to avoid runoff.
- Do not let the sprinkler run any longer than necessary.
- Apply no more than one inch of water per week on your lawn. To measure, place cake tins outside to collect rain and water from sprinklers.
- Use pistol-grip nozzles on hoses to avoid waste when watering flowers and shrubs.
- Aerate lawns by punching holes 6 inches apart. This allows water to reach roots rather than run off surfaces.
- Mow Kentucky bluegrass no shorter than 2 to 3 inches high, to hold moisture.
- Position sprinklers to water the lawn, not the pavement.
- Avoid watering on windy days when the wind not only blows water off target, but also causes excess evaporation.
- Keep sprinkler heads clean to prevent uneven watering.
- Adjust hose to simulate a gentle rain. Sprinklers that produce a fine mist waste water through evaporation.
- Know how to turn off an automatic sprinkler system in case of rain or install a rain/moisture sensor.
- Install a smart irrigation controller.
- Use an alarm clock or timer to remind you to shut off sprinklers that don't have timers.
- Use mulch around plants to hold in moisture.
- Keep weeds out to reduce competition for water.
- Water deeply using a soil-soaker or trickle-drip irrigation systems.
- Water only when needed. Check the depth of soil dryness by digging with a trowel. While the surface may be dry, adequate moisture may be retained beneath the surface.
- Do not fertilize during the summer. Fertilizing increases a plants need for water.
- Postpone planting until fall or spring when there is generally less need for water.

- Install rain barrels to catch rainwater and use for watering gardens.
- Conduct an outdoor water use audit.

### Conservation Measures for Drought Alert, Conservation, and Emergency Phases

Most outdoor watering is prohibited under emergency conditions.

In addition to the measures listed above:

- Do not allow children to play with hose or sprinklers.
- Prohibit washing driveways, vehicles, machinery, etc.
- Use leftover household water, if available.
- Delay seeding or sodding of new lawns.
- Vegetable gardens and food trees should be given minimal amounts of water on an individual basis only.
- Do not water lawns and inedible plants.
- Do not use sprinklers.

## Indoor Commercial, Industrial, and Institutional Use

### Conservation for Normal (Advisory) Conditions and Incipient Drought Phase

- Place water-saving posters and literature where employees, students, patients, customers, etc. will have access to them.
- Use hotel/motel information cards to reduce laundering.
- Identify and repair all leaky fixtures and water-using equipment. Give special attention to equipment connected directly to waterlines, such as processing machines, steam-using machines, washing machines, water-cooled air conditioners, and furnaces.
- Assure that valves and solenoids that control water flows are shut off completely when the water-using cycle is not engaged.
- Replace older toilets with 1.0 gallon per flush toilets.
- Replace older urinals with 0.5 gallon per flush urinals.
- Install showerheads that limit flow to 1.5 gallons per minute.
- Replace older residential type clothes washer with washer that meets Consortium for Energy Efficiency (CEE) specifications. CEE specifications apply to both energy use and water use.
- Install faucet aerators or metered use faucets on bathroom and kitchen faucets.
- Replace older pre-rinse spray valves with 1.6 or less gallons per minute spray valve.
- Replace water-cooled chillers and ice machines with air-cooled models.

- Eliminate single-pass cooling systems.
- Install conductivity controllers on cooling towers.
- Reduce “blowdown” on evaporative coolers, boilers, and cooling towers
- Install condensate capture and return system.
- Conduct audit of indoor water use.

### Conservation Measures for Drought Alert, Conservation, and Emergency Phases

- Reduce laundry usage or services by changing bed linens, etc., only when necessary to preserve the health of patients or residents.
- Use disposable food service items.
- Eliminate, postpone, or reduce, as may be appropriate, elective surgical procedures during the period of emergency.
- Adjust water-using equipment to use the minimum amount of water required to achieve its stated purpose.
- Shorten rinse cycles for laundry machines as much as possible; implement lower water levels wherever possible.
- For processing, cooling and other uses, either reuse water or use water from sources that would not adversely affect public water supplies.
- Advise employees, students, patients, customers, and other users not to flush toilets after every use.

## Outdoor Commercial, Industrial, and Institutional Use

### Conservation for Normal (Advisory) Conditions and Incipient Drought Phase

See recommendations for outdoor residential water use.

- Replace turf with all-weather artificial surfaces.
- Install and maintain recirculating systems in car wash facilities.
- Use recirculated water in fountains and water features.

### Conservation Measures for Drought Alert, Conservation, and Emergency Phases

Most outdoor watering is prohibited under emergency conditions.

- Prohibit use of car wash facilities.
- Prohibit washing driveways, vehicles, machinery, etc.
- Delay seeding or sodding of new lawns.
- Limit swimming pool refilling.

# Appendix G
# Local Water Shortage Response Plan

This appendix provides guidance to water utilities, municipalities, and other water providers on drought response actions and triggers for the phases of the drought response system.

## G1. Local Level Triggers

The proposed Missouri drought response system, detailed in Section 7, provides guidelines for determining the appropriate phase of the drought response system based on various indices and monitoring tools. The local drought response system should follow similar guidelines, along with the information detailed below.

- **Phase 1 – Incipient Phase**: when the DAC indicates that a water shortage might exist in the area or when local conditions indicate the potential for serious water supply shortages. Suggested indicators include:
    - Static water levels drop in wells, pumping rates decline, and/or when drawdowns increase while pumping (if supply of water is groundwater)
    - Streamflow is abnormally low, or when demand is 20 to 40 percent of flow (if supply of surface water is from springs/streams)
    - When there are 180 to 240 days of supply left available in reservoirs and impoundments (if supply of surface water is from reservoirs/impoundments)

When indications of drought and supply shortages begin to appear, water supply sources should be monitored and measurements taken at least once a week. Water quality should also be monitored. If water supply is a combination of groundwater, surface water and/or surface water from streams and reservoirs, then the values listed above should be modified accordingly.

- **Phase 2 – Drought Alert**: when the DAC indicates that a water shortage exists in the area or when local conditions exhibit visible or measurable signs that supplies are significantly lower than the seasonal norm and are continuing to diminish. Indicators that Phase 2 drought alert is needed include:
    - Signs of shortage in a well that are abnormally large or there is a rapid increase in drawdown or a large decrease in static water level
    - When demand is 40 to 65 percent of flow of springs/streams as determined from comparisons with historical records
    - When there are 120 to 180 days of supply left available in reservoirs and impoundments (more conservative numbers are appropriate for reservoirs in small watersheds)

Water supply sources should be monitored and measurements taken at least twice a week during Phase 2. Continue to monitor water quality as well.

- **Phase 3 – Conservation Phase:** when drought conditions continue to worsen, coordination with the DAC will determine when Phase 3 activities are appropriate. Indicators that Phase 3 conservation is needed include:

- If drawdown and static water level of a well continues to go down, a point should be chosen to declare an emergency situation based on prior knowledge of the well
- When demand on springs/streams is 65 to 75 percent of flow
- When there are 60 to 120 days of supply left available in reservoirs and impoundments (the time frame is especially critical for supplies in small drainage basins)

Water supply sources should be monitored and measurements taken daily during Phase 3. Water quality monitoring is even more important in Phase 3 as supply decreases.

- **Phase 4 – Drought Emergency**: when the water supply is clearly inadequate to meet predicted demands. Indicators of a drought emergency include:
  - If wells appear to be running out of water
  - When demand on springs/streams is 75 percent or more of flow
  - When there is less than 60 days of supply left available in reservoirs and impoundments.

State agencies and local governments have different responsibilities during a drought and will respond with different actions during phases of the drought response system to ensure adequate water supplies are available to residents, businesses, and agricultural producers.

## G2. Local Level Response Actions

The drought response actions for a water system will depend on local conditions including available water supplies, number of customers, potential savings from conservation measures, and other parameters. General guidance on proper drought response for local water systems is provided below.

- **Phase 1 – Incipient Drought**: issue a water shortage advisory as indicated by the DAC or as local conditions dictate. Set conservation goals, notify the affected public of the potential problem, and request voluntary conservation (expressed as a percentage of normal use or a specific gallon amount). Enlist support from the local Water Shortage Management Team and develop action plans for alternate supply sources. Establish water conservation ordinances that have enforceable measures for non-compliance.

- **Phase 2 – Drought Alert**: issue a water shortage alert as indicated by the DAC or as local conditions dictate. Set more stringent conservation goals, which can include activities to educate utility owners and operators that water loss must be measured and reduced to a reasonable limit. Inform the public of the problem using an intensive public information campaign, restrict Class 3 non-essential use (see Appendix H – Suggested Drought Response Prioritization of Water-Use Classes), and request voluntary conservation of all other water use. Monitor and enforce compliance of water restrictions or incorporate enforceable water use restrictions into a water conservation ordinance if not previously done. Develop a firm commitment to alternate supply processes such as pipelines, water hauling, and/or agreements with nearby water suppliers.

- **Phase 3 – Conservation Phase**: issue a water shortage statement with coordination from the DAC. Set even more stringent conservation goals than in Phase 2, restrict Class 3 use and ration Class 2 use, expand educational efforts to include explaining pricing measures and restrictions, and put water conservation ordinance into place if not previously done. Assess penalties for non-compliance with

the water conservation ordinance with increasing penalties for repeat violations. Alternate supply sources should be put into service.

- **Phase 4 – Drought Emergency**: begin mandatory allocation of water and advise the DAC of local emergency. Immediately reduce usage by 25 to 50 percent through use of stricter conservation pricing, conservation goals, and banning Class 2 and 3 water use. Monitor all shortages and compliance with water conservation ordinances, penalize non-compliance, and enforce allocations as necessary. Ensure fair and equitable water rationing is occurring and use the method most appropriate for the local community to determine allocations. Set maximum allowable usage and maximum per capita use. Secured water allocation to individual users would only occur at times when the water supply is almost totally depleted and would only be for life-threatening cases. During extremely severe drought, the Governor should, at the recommendation of the DAC, declare mandatory allocation of water in communities not adequately responding to water shortages.

Provisions for limiting installation of service to new customers may need to be considered where the addition of new customers would cause impairment of existing service to tenured customers in the form of low water pressure, bacterial contamination, and/or increased costs to original customers. Limitation of service to new customers should be reviewed on a case-by-case basis with human health and safety being the primary factor.

  - Individuals who previously refused service during normal, non-drought conditions
  - Normal construction of new residential dwellings and refurbishment of existing dwellings that would typically require public water service hookup under normal conditions
  - Normal business or industrial construction or development where public water service would be required
  - Pre-planned and previously approved water service expansion, long-term implications for an area's economic, social, and environmental stability and growth.

When the drought conditions start to ameliorate, the drought response phases should be decreased in reverse order of implementation. It is advised to maintain a buffer period prior to returning to a lower phase in drought response system to ensure that drought conditions continue to improve sufficiently. Water shortage response efforts, and results of those efforts, should be recorded and evaluated for use during future drought events.

# Appendix H
# Suggested Drought Response Prioritization of Water-Use Classes

The drought response system for local water response plans should incorporate a categorization system for types of water use. These categories, or water use classes, clarify the need for prioritization when developing and enacting water restrictions and ensuring adequate supply is always available for essential water uses.

## Class 1: Essential Water Uses

The following are uses of water deemed necessary and should be supplied at all times:

- Residential Indoor Use: Water in amounts reasonably needed to sustain human life, and to maintain reasonable standards of hygiene, cleanliness, and sanitation
- Health Care Facilities: Patient care, rehabilitation, and other health-related needs
- Firefighting
- Water that is necessary for health and public protection purposes, as specifically approved by the health official and the municipal governing body, should include public water supply and wastewater treatment
- Water that is necessary for the operation of electric power generation, essential for the operation of key military facilities, data communication centers, and other critical facilities and infrastructure.,

## Class 2: Socially or Economically Important Uses of Water

To the extent that sources of water other than fresh water are not available or feasible to use, socially or economically important uses of water include:

- Agricultural irrigation for the production of food and fiber and the maintenance of livestock
- Watering by commercial nurseries at a minimum level to maintain stock
- Water uses by arboretums and public gardens of national, state, or regional significance where necessary to preserve specimens
- Water use by sod producers and the turf industry to a minimum level to maintain stock
- Use of fresh water at a minimum rate necessary to implement revegetation following earth moving, where such revegetation is required pursuant to an erosion and sedimentation control plan adopted pursuant to law or regulation
- Commercial laundromats
- Restaurants, clubs, and eating establishments
- Schools, churches, motels/hotels, and other commercial establishments

- Commercial air conditioning (e.g., office buildings, shopping centers, etc.), including refilling for start-up at the beginning of the cooling season, make up water during the cooling season, refilling specifically approved by health officials and the municipal governing body where the system has been drained for health, protection, or repair purposes
- Industrial production processes and cooling

### Class 3: Nonessential Uses of Water

Nonessential uses of water include:

- Outdoor commercial and non-commercial watering (public or private)
- Fountains, reflecting pools, and artificial waterfalls used for ornamental purposes
- Gardens, lawns, parks, playing fields, and other recreational areas that do not have access to recycled water supplies
- Filling and operation of swimming pools (public or private)
- Watering of golf course greens to the extent that sources of water other than fresh water (e.g., recycled water) are not available or feasible to use
- Washing of all motor vehicles including commercial car and truck washes and private vehicles by owner except in cases involving recognized human health and safety concerns (e.g., ambulances, commercial vehicles that haul fresh produce, etc.)
- Use of fire hydrants and sprinkler caps for testing any fire apparatus and for fire department drills (unless specifically approved by the health officials of the municipality). In general, the use of fire hydrants for all purposes except for firefighting, health protection, or certain testing and drills by the fire department if it is in the interest of public safety and is approved by the governing body.
- Any flushing of sewers and hydrants except as needed to ensure public health and safety, and approved by health officials and the governing body

# Appendix I
# Post Drought Evaluation Procedures

## Drought Assessment Committee (DAC) Post-Drought Evaluation

The DAC may perform post-drought evaluation by addressing the following questions as a part of the evaluation process:

- Was the drought response system followed? If not, why?
- Were the actions taken and measures implemented effective in mitigating the impact or the drought? Which actions and relief measures were effective, and which were not?
- Should the plan have included other actions or assistance measures?
- Did aid reach all affected groups in the stricken area? If not, why not? How were the target groups for aid identified?
- Were the measures timely in relation to the events of the drought period?
- Was it possible to correct errors during the emergency?
- What financial and human resources were allocated to the relief effort?
- Where did the resources come from and how were they controlled?
- How efficient was the logistical support and the available infrastructure? What obstacles were encountered that reduced the efficiency of the response?
- How effective was the coordination of state and federal response efforts? How did this cooperation affect the flow of information or assistance?
- Was media coverage accurate and realistic in providing details of the event? What kinds of media were involved? What role did they play in the emergency?

## Utility Level Post-Drought Evaluation

The following after drought actions provide a post-drought evaluation review designed by the USEPA to assist in evaluating drought response. These actions are from the EPA Drought Response and Recovery: A Basic Guide for Water Utilities (EPA Office of Water 2016) and are presented by categories designated in the Guide. Water utilities are encouraged to perform a post-drought evaluation to assess response actions and identify areas for improvement. While it is understood that some evaluation actions may not be applicable or financially feasible to all utilities, they are intended to provide guidance during the evaluation process.

### Drought Response Team and Utility Staffing – After the Drought:

- Write an after action report that describes effective drought response actions and areas that could be improved.
- Identify new standard operating procedures for future water shortages and for routine operations.
- Keep your drought response team active by conducting drought preparedness activities.

### Drought Response Plans – After the Drought:

- Revise your drought response plan based on lessons learned, considering the following:
    - Did the drought stages, triggers and demand reduction measures achieve the anticipated results?

  - Were the demand reduction measures too prescriptive, or did they not provide enough direction to customers?
- Incorporate drought resilience plans or projects into multiyear capital improvement plans and budgets.
- Conduct a debrief with utility staff and partners shortly after the drought to discuss the effectiveness of and improvements to response activities.

### Training and Exercising on Drought Response – After the Drought:

- Schedule an annual tabletop exercise to practice different drought scenarios. Potential topics include:
  - Requirements for hauling potable water, including availability of tanker trucks, hauling routes, truck disinfection, maintenance and operational procedures for introducing water into the system.
  - Identifying additional water sources or operational changes to expand water supplies.
  - Procedures for communicating with customers and large water users.

### Funding and Financing Considerations – After the Drought:

- Revenue recovery can be difficult, as water use may never come back to pre-drought levels. Working with local, county and state officials may help secure funding and technical assistance if you implement large projects to build longer-term drought resilience, such as new groundwater wells and interconnections.
- Continue to engage with state officials to get approval for a surcharge (if required), so that you will be able to activate it if needed during future droughts.

### Water Supply and Demand Management – After the Drought:

- Continue or increase monitoring activities to maintain a full awareness of the condition of your water supply.
- Develop a plan to implement projects that address your long-term needs so your utility is more resilient to future droughts.

### Improve System Efficiency – After the Drought:

- Continue to implement your leak detection and repair program that ensures a prompt response mechanism for utility staff to make repairs. Prioritize and repair or replace components in the water distribution network that could lead to leaks.
- Look for other ways to use water efficiently throughout your utility or other departments, such as installing low-flow fixtures, retrofitting landscapes and replacing inefficient irrigation systems.
- Initiate a program to conduct annual water loss audits.

### Identify Where Water Demand Can Be Reduced – After the Drought:

- Designate a water efficiency coordinator to manage and implement treatment and distribution system efficiency measures, and provide public information about water-saving practices to customers. This can be a part-time position and could be held by the same person designated to monitor drought conditions.
- Document how water demand in the system changed during drought response. Look at your production data to estimate the lag time between announcing reduction goals or mandating water use restrictions, and seeing a change in water use. This information can help you revise trigger levels for when mandatory restrictions are established.
- Establish a year-round conservation program that promotes water-saving habits and encourages customers, especially large water users, to adopt water conservation strategies in their day-to-day operations.

- Consider including the following water use efficiency measures and programs in a year-round demand management program:

### *Policies, Service Rule Provisions, Ordinances and Building Codes*

- Adopt an ordinance that would prohibit wasting water from sources such as customer leaks, runoff from driveways and sidewalks or irrigation overspray.
- Establish a minimum number of cycles of concentration for cooling towers.
- Establish year-round lawn and landscape irrigation schedules (with set time of day or days per week).
- Establish annual irrigation inspections for automatic sprinkler and irrigation systems.
- Promote the adoption of local building, plumbing, landscaping or other codes that specify water and energy efficiency standards required for new construction, irrigation systems or landscaping.
- Require that leak inspection and repair be conducted prior to property resale or lease.
- Require residential fixture and equipment retrofit or replacement upon property resale or lease.

### *Demand Management: Potential Conservation and Efficiency Measures*

- Offer online or onsite water use and water efficiency check-ups and water-saving tips for your customers (landscapes, irrigation systems and indoor uses).
- Install hydrant locks to reduce water theft after coordinating with and providing training to local fire department responders.
- Set up rebate, distribution or installation programs for WaterSense or ENERGY STAR certified high-efficiency toilets, clothes washers, shower heads, water heaters, irrigation technology or other water-saving appliances. The amount of water savings will be determined by conditions specific to your area. A benefit-cost analysis is recommended prior to implementing any rebate program.

### *Additional Residential Conservation and Efficiency Measures*

- Set up a water softener replacement program.
- Encourage installation of rain or freeze sensors for irrigation systems.
- Establish landscape and turf or irrigation system replacement programs.
- Encourage customers to report or repair leaks on their side of the meter.
- Consider offering incentives to the biggest water savers. Possible incentives include prizes, billing credits or other recognition.

### *Additional Commercial, Industrial and Institutional Conservation and Efficiency Measures*

- Set up rebate, distribution or installation programs for WaterSense or ENERGY STAR certified high-efficiency urinals, commercial dishwasher systems or pre-rinse spray valves, ice machine replacement or similar appliances.
- Implement cooling tower audits.
- Set up a commercial vehicle washing and car wash system replacement program.
- Establish a rainwater capture or condensate reuse incentive program.

## Identify Additional Water Supplies – After the Drought:

- Explore alternative sources and adopt creative strategies for managing existing supplies to enhance long-term reliability.
- Engage with ongoing statewide or regional water planning processes to be sure that your water supply needs and preferred projects are covered by those plans.
- Consider initiating a countywide or watershed-wide water planning process to collaborate on cost-effective and sustainable long-term water supply solutions, so that you are better prepared for the next drought.

### Communication and Partnerships – After the Drought:

- Coordinate with other local utilities and agencies to announce the end of the drought emergency and water restrictions.
- Keep communicating frequently and frankly with all of your customers about the utility's drought recovery progress, including any changes to rates.
- Communicate the importance of your customers' continued support. Reframe messages from a focus on drought response to a focus on long-term water supply reliability. Continue to stress the importance of conserving water, actions the utility is taking, and actions the public can take. Partnering with EPA WaterSense can provide access to materials that help with communications.
- Engage with large water users and local businesses to help them prepare for the next drought.

### Role of Partnerships – After the Drought:

- Maintain relationships with the partners that you worked with during response. Continued coordination with your partners will help ensure the effectiveness of future drought response and long-term water supply planning efforts and will benefit your utility's other ongoing decision making, operational and regulatory activities.
- Work with local, county and state officials to help find technical and financial resources to support drought recovery and resilience projects.

## Reference:

US Environmental Protection Agency, Office of Water. March 2016. EPA Drought Response and Recovery: A Basic Guide for Water Utilities. MC 4608T.  EPA Report 810-B-16-001.

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